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PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

Volume 117

NUMBER 2

SECTION A: Papers from the Third International Symposium
on the Silurian System:
The Sir Frederick McCoy Symposium
Orange, New South Wales, July, 2000

PAPERS FROM THE THIRD INTERNATIONAL SYMPOSIUM ON THE SILURIAN SYSTEM: THE SIR FREDERICK MCCOY SYMPOSIUM

INTRODUCTION

THE THIRD International Symposium on the Silurian System was held as part of the Palaeontology Down Under congress in Orange, New South Wales. The congress, organised by the Macquarie University Centre for Ecostratigraphy and Palaeobiology, was attended by 122 participants. A broad spectrum of research themes was explored in five symposia, several of which have resulted in published collections of papers (Talent & Mawson in Laurie, 2002).

The Silurian Symposium paid tribute to Sir Frederick McCoy (c. 1823–1899), an illustrious natural historian, in recognition of his decisive role in delimiting the Silurian and documenting its fossils. The present collection of papers was presented at the Symposium or explores relevant themes in Silurian-Devonian palaeontology.

McCoy's role in the great Cambrian-Silurian debate of the 19th Century and his pioneering work in recognising the Silurian in Australia are the focus of a paper by Doug McCann and Neil Archbold. They recount how McCoy's palaeontological research in Britain provided the breakthrough that allowed Sedgwick's Cambrian System to conclusively be distinguished from Murchison's all-encompassing Silurian. As a professor at the University of Melbourne and later as Director of the National Museum of Victoria, McCoy made major strides in demonstrating that the geological time scale developed in Europe was applicable in Australia and is, indeed, a global phenomenon.

The Silurian rocks of Victoria were scrutinised by McCoy and his colleagues at the then newly-founded Geological Survey. The complex tectonic history of the Victorian Silurian succession remains a lively field of study. John A. Talent and coauthors present conodont faunas from carbonate units in the Silurian of eastern Victoria, and explore the chronological and tectonic implications of these new data. The precise temporal framework provided by the conodonts contributes to resolving whether several controversial limestone units are allochthonous or autochthonous, as well as setting constraints on the duration of the Benambran Orogeny in its type area.

Carlton E. Brett and David C. Ray present a case study in sequence and event stratigraphy for the Silurian in North America that will serve as a model for field-based sequence stratigraphic studies in other parts of the world, including Australia. Their paper draws correlations between the well-exposed Llandovery and Wenlock units in the Cincinnati Arch and coeval strata in the Appalachian Basin of New York and Ontario. Broad-scale regional correlations of sequences and their bounding surfaces, integrating event beds and biostratigraphy, suggest that eustatic sea level controls the development of sequence boundaries over a broad geographic extent on the Laurentian craton.

Frederick McCoy was highly regarded for his monographic taxonomic treatments of Australian Palaeozoic fossils. James Valentine's taxonomic study of Early Devonian brachiopods from the Buchan Group of eastern Victoria carries on this tradition (indeed, the first palaeontological work on the Buchan limestones was undertaken by McCoy himself). Valentine documents 35 species of brachiopods from the Murrindal Limestone, one of the richest Devonian brachiopod faunas in eastern Australia. The taxonomic composition of the silicified Murrindal faunas is most similar to Emsian faunas from the Taemas-Wee Jasper area of New South Wales.

I am indebted to John A. Talent, who inspired our colleagues to contribute excellent papers for this volume.

Gregory D. Edgecombe

TALENT, J.A., & MAWSON, R. 2002. Preface. In *Palaeo Down Under Conference. Papers from the conference held at Kinross-Walaroi School, Orange, New South Wales, July 2000*, Laurie, J.R., ed, *Association of Australasian Palaeontologists, Memoir* 27.

FREDERICK MCCOY AND THE SILURIAN SYSTEM

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MCCANN, DOUG & ARCHBOLD, N. W., 2005. Frederick McCoy and the Silurian System. *Proceedings of the Royal Society of Victoria* 117(2): 151–173. ISSN 0035-9211.

The foundation of the Silurian system in 1835 by Roderick Murchison and the subsequent publication in 1839 of his monumental work *The Silurian System* (along with its accompanying map) is generally recognised as a landmark in the progress of global stratigraphy. The physical structure, composition, fossil content and stratigraphical order of these previously obscure Lower Palaeozoic strata were now made manifest and thus available for correlation within Great Britain and Continental Europe and, eventually, worldwide. Murchison's Silurian system was rapidly accepted by the majority of geologists as the major period of the Lower Palaeozoic. Murchison's triumph, however, brought him into conflict with his former friend and collaborator Adam Sedgwick who accused him of overextending the lower boundary of the Silurian and encroaching on geological territory which was rightly part of the Cambrian system. In 1835 Sedgwick had proposed the Cambrian system directly following Murchison's declaration of the Silurian system. The Cambrian-Silurian debate escalated into one of the longest running and most bitter disputes in 19th Century geology.

Irish-born Frederick McCoy, who published *The Silurian fossils of Ireland* in 1846, later became embroiled in the Cambrian-Silurian debate while working as Sedgwick's palaeontological assistant. It was McCoy who established that Sedgwick's Cambrian system contained its own distinct fossil assemblages and could justifiably be separated out from Murchison's all encompassing Silurian. Following his emigration to Australia in 1854 McCoy recognised the Silurian and Cambrian locally, and then went on to validate the presence of other major European systems, such as the Cretaceous and the Devonian, along the length of the geological column. McCoy was therefore the first to confirm unequivocally that the geological column was a coherent global entity.

Keywords: Lower Palaeozoic, Silurian, Stratigraphy, Cambrian

IN 1839 Roderick Murchison (1792–1871) published his monumental work *The Silurian System*, one of the most significant geological publications of the 19th Century. As well as launching the Silurian system as a pivotal stratigraphical unit in the Palaeozoic Era it helped confirm Murchison's status as one of the world's most pre-eminent geologists. Murchison's global influence in geology is difficult to overestimate. He was the founder of the Silurian system, founder of the Permian system and with Adam Sedgwick co-founder of the Devonian system. His Silurian system rapidly received international acceptance. Frederick McCoy (c. 1823–1899: Figs.1, 2 herein) was a young man when Murchison published *The Silurian System* but as he gained experience and insight as a novice palaeontologist he was suitably awed by Murchison's achievement. Under Adam Sedgwick's tutelage he later came to question some of Murchison's interpretations. McCoy, in fact, made the vital breakthrough which led to a reconsideration of the evidence of just where the lower boundary of the Silurian period lay and paved the way for the recognition of a legitimate and distinct Cambrian period as Sedgwick had long advocated. This key insight was a first step in an eventual resolution of the debate. McCoy went on to play a leading role in the correlation of the stratigraphical periods in Australia, including the Silurian, with corresponding European and North American units.

The Silurian period as defined in the early 21st century is a greatly reduced entity in comparison with that delineated by Murchison in the mid 19th century. It is now the shortest period in the Palaeozoic Era, covering a span of some 28 million years (International Commission on Stratigraphy 2004, from Gradstein et al. 2004) — about half that of the other major periods which are all in the vicinity of about 50 million years duration. At its zenith in the 1840s Murchison's Silurian system included everything below the Devonian down to the top of the basement rocks of the 'Azoic' (or in modern terms the Precambrian) — amounting to about 150 million years duration or about half of the Palaeozoic Era. In retrospect, Murchison's fear that if he compromised

Fig. 1. Lithograph of Frederick McCoy by Frederick Schoenfeldt, signed by Frederick McCoy; from a series entitled 'Notable Men of our time'. Published by Hamel and Co., c. 1859. La Trobe Picture Collection, State Library of Victoria.

on the extent and boundaries of his Silurian system his hard won geological territory would be in grave danger of becoming "attenuated" proved to be well founded. Within a few years of Murchison's death the suggestion was made by Charles Lapworth that a new period, the Ordovician, be substituted in the place of his Lower Silurian (Lapworth 1879). This proposal gradually gained international acceptance and Murchison's once vast Silurian was whittled down to its present size.

The establishment of the Silurian system by Murchison and of the broader ordering of the stratigraphical rock sequence as a whole was one of the major achievements within geology in the 19th century. Murchison's demarcation of the Silurian rocks was a milestone in the development of stratigraphical palaeontology especially in its application as an indispensable aid to geological mapping. Some notion of the rapidity with which the Silurian system was adopted throughout Europe is indicated by its inclusion into Grigorii Petrovich Helmersen's Geological Map of European Russia in 1841 (Hecker 1987). Murchison clashed with Sedgwick on, among other things, the issue of fossils versus lithology as being satisfactory and sufficient indicators of a geological period. Frederick McCoy, who was just beginning to establish himself as a capable palaeontologist at this juncture in the late 1830s, later became involved in the debate and provided further evidence that fossils, if available, can indeed be definitive indices for the demarcation of the geological time scale, just as Murchison was arguing. Nevertheless, it was Sedgwick rather than Murchison who benefited most from McCoy's palaeontological work.

McCoy's early career in Ireland

Little is known of Frederick McCoy's early education (Darragh 2001: 160). There is also some uncertainty about his exact date of birth; however, he later testified several times that he developed an interest in natural history at a very young age. He was only a young teenager when he published his first paper — on ornithology, for which he retained a life-long interest. The paper was titled 'Remarks on Mr Eyton's arrangement of the Gulls' (McCoy 1838), published in the *Magazine of Natural History*. Typically for McCoy his initial paper addressed some of the finer points of biological classification and nomenclature. In 1839 he joined the Geological Society of Dublin and began to specialise in the study of fossils. He was appointed assistant to Dr John Scouler one of the Society's secretaries and helped arrange the fossil collections in the Society's Museum (Griffith 1841). As Darragh (2001: 160) notes, Scouler, who was a noted naturalist and Professor of geology, zoology and palaeontology at the Royal Dublin Society, must have been an important early influence on McCoy. It was also in 1839 that McCoy published his first paper on fossils. He described a Carboniferous ostracod and named it after his mentor *Entomoconchus scouleri*.

His work for the Geological Society of Dublin required him to curate and arrange the fossil collections of the Museum. In 1841 he arranged for sale the Henry Charles Sirr collection of shells and fossils as well as curating the collections of the Geological Society of Dublin and the Royal Dublin Society. In addition, by this time McCoy was also deeply involved in palaeontological work for Richard Griffith (1784–1878) who was primarily responsible for the production of the first complete geological map of Ireland. McCoy was commissioned by Griffith to work on the extensive Carboniferous Limestone fossil collections made by Griffith and his staff of the Boundary Survey of Ireland. Griffith needed these fossil determinations to establish the relative ages of sedimentary strata for the compilation of his Geological Map of Ireland. McCoy described some four hundred and fifty new species of fossil organisms. After some delay the results were published in a monograph in 1844 as *A Synopsis of the Characters of the Carboniferous Limestone Fossils of Ireland*.

An examination of the list of the fossil descriptions included in McCoy's book on the Carboniferous indicates the scope of his abilities at a relatively young age (Archbold 2001). Fossil phyla covered included (in modern taxonomic terms) Cephalopoda, Gastropoda, Bivalvia, Conulata, Brachiopoda, Trilobita, Ostracoda, Annelida, Echinodermata, Coelenterata and Bryozoa. Obvious also is McCoy's talent as a natural history artist. Archbold judges that "his illustrations of new species were also of exceptional quality for their time". They were drawn as realistically as possible, usually showing the imperfections of the specimens and less simplified than, say, Phillips (1836, 1841) or less idealised than, say, de Koninck (1842) or those of other comparable authors of the time. It is significant that von Zittel (1901: 451) in his *History of Geology and Palaeontology* remarks that the publications of de Koninck, Phillips and McCoy

were 'still the basis of all European research on the faunas of the Carboniferous limestone'. McCoy's works are still regarded as being classic contributions to palaeontology (as, for example, his contributions on the study of Palaeozoic corals (see Ivanovskii 1973)).

Further work for Griffith carried out by McCoy resulted in a second book *A Synopsis of the Silurian Fossils of Ireland* published in 1846. Seventy new species were included and as with the previous book about 12 phyla were described in total. As Archbold (2001) notes, McCoy possessed an exceptional knowledge of the earlier and contemporary palaeontological literature of both British and continental European workers. Adam Sedgwick, who first met McCoy while on a visit to Dublin in 1841, later said of McCoy that "no one of my friends…has so large an historical knowledge of foreign works on Palaeontology".

During his work on the Irish Silurian McCoy became thoroughly acquainted with Roderick Murchison's research and thinking. Of necessity, one of the main reference works McCoy consulted was Murchison's authoritative *Silurian System*. Griffith had delayed publication of the *Silurian Fossils of Ireland* in the hope that he would have the opportunity to write a description of the geology of the collecting localities. Unfortunately this expectation was not realised and in the meantime Murchison and colleagues published his second major opus *Geology of Russia* which included details of the Silurian geology and fossils of Russia, the latter largely by de Verneuil. This forced Griffith to instruct McCoy to revise his already completed fossil determinations. Griffith explained this situation in his introduction (or 'Notice') at the beginning of the *Silurian Fossils of Ireland*:

> "The following Synopsis of Fossils collected by me from the several Silurian districts of Ireland, was completed by Mr M'Coy in the month of May, 1845, but its publication was delayed, in the expectation that, in the intervals of public duty, I should have had the leisure to prepare a Memoir descriptive of the Geology of the several localities, and thus render the work more perfect and useful. Unfortunately, I have been disappointed in this expectation, and, in consequence, have determined to print it in its present form. In the interval which has elapsed between the completion of the Synopsis and the present time, Sir Roderick Murchison's splendid and admirable Work on the Geology of Russia has appeared, and with it the labours of M. de Verneuil and Count Keyserling on the Palaeozoic Fossils of Russia, &c., many of which occur in the Irish deposits. At my request Mr M'Coy has revised his Manuscript, and introduced the improvements in nomenclature proposed and adopted by those distinguished Palaeontologists" (Griffith, in McCoy, 1846).

In 1845 the Geological Survey of Ireland was established under Captain Henry James as the Irish Local Director. James was accountable to Henry De la Beche who as Director General of the Geological Survey of England and Ireland issued a set of instructions on the type of observations that were to be made in the field (Herries Davies 1983: 127). McCoy was the first field-surveyor appointed to the Irish Survey. James hoped to utilise McCoy's already significant palaeontological experience for the determination of the fossils collected by the Survey's Irish staff but De la Beche insisted that they should be sent to London for examination by the palaeontologist Edward Forbes (Darragh 1992). In lieu of doing fossil determinations McCoy instead was sent out into the field and was responsible for the production of some of the Irish Survey's very first maps. Many years later in 1889 giving evidence to a Royal Commission on Coal for the Victorian government, McCoy recalled:

> "Yes, I was a member of the Imperial Geological Survey, and made in the field the geological maps of several counties, entirely by myself, for the British Government, according to the methods of the Imperial Geological Survey, which is considered the best in existence; and then, from a very early period of my rather long life, I have devoted myself to a branch of geology [i.e., Palaeontology] which I found people had not sufficiently acquainted themselves with…and before coming to this colony I had already established myself as an authority upon that branch of geology…." (McCoy 1891)

It might seem from the above quotation that during the early period referred to McCoy was happily engaged in field-work and mapping activities but this was far from the case. This was a troubled period for McCoy. Unfortunately for McCoy, Henry James who was pleased with McCoy's work resigned in 1846, and he was replaced by Thomas Oldham (1816–1878) with whom McCoy had previously quarrelled at meetings of the Geological Society of Dublin. Oldham had criticised McCoy's work on the fossils of the

Carboniferous and McCoy had vigorously defended himself. Aware of this antagonism, James, as one of his last actions as Local Director wrote to De la Beche stating that '…it is clear that Oldham's appointment as Local Director, makes McCoy's position particularly unfortunate, and I should think it would be advisable to remove him to England.' De la Beche, however, for whatever reason chose to ignore James' advice.

Oldham, who later moved on to a distinguished career as head of the Geological Survey of India, was soon chastising McCoy for numerous errors, omissions and careless work. This, incidentally, was not the first time McCoy had been accused of shoddy work. In 1842 he had lost his position at the Geological Society of Dublin because of alleged neglect of his curatorial duties. At that time he was deeply involved with his work for Richard Griffith and this may have left him open for criticism (Darragh 2001: 161). Oldham had been McCoy's successor as curator of the Geological Society of Dublin. Under Oldham's supervision at the Irish Survey, McCoy's position became increasingly untenable. Following James' departure McCoy attempted to find alternative employment and applied for several jobs but was not successful.

It is difficult from this distance in time to judge the relative merits of the accusations by Oldham against McCoy but in making an assessment several points need to be considered. Firstly, there was undeniably considerable hostility between them which probably coloured the issues. Secondly, as Herries Davies (1983: 142) points out, 'One of McCoy's problems in 1846 may have been that he was inadequately briefed as the duties of a field-geologist. De la Beche's *Instructions* of May 1845 had been singularly unhelpful in this respect'. This problem was compounded by the fact that James himself seemed to have little idea of what was necessary. Herries Davies (1995: 34) comments that, 'One must, nevertheless, have some sympathy with M'Coy. Neither he nor any other of the Survey's officers, would seem to have received any clear instruction from James as to the nature of their duties.' Thirdly, James had hired McCoy hoping to draw upon his palaeontological skills. McCoy had similar expectations himself. He was much more oriented towards the identification and classification of fossils than field mapping *per se*. Nevertheless, despite McCoy's difficulties during this period they seem to have had little negative impact on his future career.

McCoy at Cambridge University

In an attempt to extricate himself from his predicament at the Geological Survey of Ireland, McCoy wrote to Adam Sedgwick (1785–1873) the Woodwardian Professor of Geology at Cambridge University, who at that time was in need of a palaeontologist. Sedgwick was impressed with McCoy, later stating that, '…when I first saw him (in 1841) he had nearly completed his volume on the Carboniferous Fossils of Ireland. His Irish works put him in the front rank of British palaeontologists' (Sedgwick and McCoy 1855: xvi). In November 1846 Sedgwick wrote back to McCoy and offered him employment. He was invited to arrange the collections in the Woodwardian Museum at Cambridge. Sedgwick was confident that McCoy would be equal to the task. Commenting on his first interactions with McCoy, Sedgwick recalled that,

> "When my friend formed his first engagement with this University, he came amongst us young indeed in look; but, even then, a veteran in Palaeontology. He was well trained and ready for the task he had undertaken; and far better stored with a knowledge of the foreign standard works on Palaeontology than any man with whom I had before conversed" (Sedgwick 1855: xvi).

The Woodwardian Museum housed a large collection that was originally established by a bequest by John Woodward (1665–1728) more than a century earlier. The original collection had been added to considerably over the ensuing years, including many specimens collected by Sedgwick and his students over three decades. Sedgwick also supplemented and expanded the collection by the purchase of other geological collections and selected individual specimens to develop one of the finest geological museums in the world (Rudwick 1975: 276).

Initially Sedgwick could only offer McCoy guaranteed employment for one year but this was extended to three years so that he could complete his arrangement of the Museum's palaeontological specimens, both British and foreign. In total they collaborated on the project for nearly eight years; for the first three years McCoy worked fulltime, then part-time. In 1849 McCoy was appointed to the Foundation chair of geology and mineralogy at Queen's College Belfast. His duties included responsibilities as Curator of the Museum, but he continued to travel back to Cambridge to work on the collections during vacations. Sedgwick reported that McCoy approached his work with

enthusiasm and "almost incredible labour and perseverance" (Sedgwick, quoted in Darragh 1992: 17). To give some idea of the extent of McCoy's work, Sedgwick, quoting from the Cambridge University Commission's *Blue Book* of 1852, remarks on McCoy's work on Count Münster's fossils — just one of the collections held by the Woodwardian Museum — as follows:

> "Some notion may be formed of the greatness of his task when it is stated, that Count Münster's duplicates amount to more in number than 20,000, and that they form but a minute fraction of the great Palaeontological series Professor M'Coy has now arranged stratigraphically in the Museum" (Sedgwick 1855: vii)

Sedgwick further testified that towards the completion of the project "Professor McCoy was employed upon the Collection, not only during long hours of the day, but frequently during the late hours of the night" (Sedgwick 1855: viii). Initially released in three parts (McCoy 1851, 1852, 1855) this work on the British Palaeozoic fossils was collectively published as A Systematic Description of the British Palaeozoic Rocks and Fossils in the Geological Museum of the University of Cambridge (1855), a comprehensive and significant work in the history of palaeontology. One of McCoy's contemporaries, Professor Heinrich Bronn of Heidelberg welcomed the book as "one of the most important appearances in the literature of Palaeontology" (Fendley 1969: 134), and as Sedgwick remarked in the Introduction, "Whatever may be the merits of the following work, it is one of enormous labour."

It is clear that Sedgwick was very pleased with McCoy's contribution, describing him as "one of the very best palaeontologists in Europe". However, it was not just McCoy's important and wide-ranging contribution to systematic palaeontology, or his dedicated work in organising the collections in the Woodwardian Museum, that elicited Sedgwick's fulsome praise — he had another much more personal reason to be grateful to McCoy. For a number of years before he hired McCoy, Sedgwick had been locked in an increasingly frustrating and bitter geological dispute with his former friend and collaborator, Roderick Impey Murchison. Because of his association with Sedgwick, McCoy also, incidentally, and probably reluctantly, became involved in the debate, but nevertheless played a decisive role in its eventual resolution.

The Development of Stratigraphy in Britain

By the beginning of the 19th century in Britain it was generally accepted that the earth's rock strata were more or less in regular order as suggested by a variety of indicators such as lithology, mineralogy, morphology and organic remains. With the founding of the Geological Society of London in 1807 the organisation and order of the rock strata became a major focus for British geologists. Indeed, as a number of authors have pointed out (for example, Porter 1977: 181), most British geologists in the early to mid 19th century were stratigraphers or in some way supporting stratigraphical activities. At this time the term 'geology' became virtually synonymous with 'stratigraphy'.

Following the publication of William Smith's geological map of England and Wales in 1815 and George Bellas Greenough's improved version in 1820 considerable attention was placed by the members of the Geological Society on gathering more comprehensive and reliable geological data from all over Great Britain. Geological mapping of the rock sequences in Britain began in earnest in the early 1830s chiefly due to the work of Henry De La Beche, who was appointed as first director of the Geological Survey of Great Britain in 1835, and work accelerated in the 1840s as the number of staff members of the Survey increased.

A parallel and necessary development that accompanied the production of useful and accurate geological maps was the growing understanding that 'organic remains' or fossils were critical indicators in determining the relative age and order of the stratigraphical rock sequences. In the early years of the development of the science and art of stratigraphy, it was lithology and geological structure that were the chief criteria in the recognition of major rock units and therefore of geological time units — for example, the term 'Jurassic' was applied to strata that corresponded to the Jura limestone; similarly, 'Cretaceous' for the chalk beds, 'Carboniferous' for the Coal Measures, and so on — however it became progressively apparent that many sedimentary rock units contained recognisable and distinct fossil faunas and floras and these could often be used to unambiguously determine the order of succession and relative ages of the strata. As a result, palaeontology increasingly came to be appreciated as an essential practical tool in geological mapping.

The use of fossil organisms for the elucidation of the age and order of sedimentary rock sequences

is known as *biostratigraphy* or *stratigraphical palaeontology* and its establishment as a sub-discipline within geology was an important step in the development of a number of related fields such as historical geology, sedimentology, economic geology and evolutionary biology. Zittel (1901) provides an early authoritative account of the history of stratigraphy. Other useful references include Berry (1968) and Gohau (1990). A succinct but inclusive article on the development of the Geological Time Scale is given by Branagan (1998).

Adam Sedgwick

One of the most important early contributors to the mapping of Britain's rocks was Adam Sedgwick (1785–1873), who was elected as Woodwardian Professor of Geology at Cambridge University in 1818. Although Sedgwick must have had at least a passing interest in geology as evidenced by his attendance at a meeting of the Geological Society of London in 1816 (Speakman 1982: 56; Woodward 1907: 39) his formal training and experience in the subject were minimal prior to his election. Trained in the classics and mathematics and ordained in 1817 he was favoured for the post as Professor of Geology more for his general academic and personal qualities than for any specialised geological knowledge he may have possessed at that time. Nevertheless, from the outset he embraced his new role with keen anticipation and zeal. He became a fellow of the Geological Society of London and carried out his first geological excursion in the summer of 1818 (Rudwick 1975: 275). The following year he began a course of lectures on geology which proved to be popular, influential and enduring. This celebrated lecture series was repeated annually until 1870; a period of over fifty years.

Sedgwick soon made up for his lack of experience and expertise in geology by familiarising himself as far as he was able with all aspects of the discipline. Within a few years he was presenting and publishing noteworthy papers and also developed a reputation as a superb field geologist. He was president of the Geological Society of London from 1829 to 1831, and of the British Association when it held its first meeting at Cambridge in 1833. Perhaps reflecting his mathematical background Sedgwick is reported to have had an uncommon ability to visualize and reconstruct geological structures and sequences based on specific but limited information such as strike and dip measurements, jointing patterns, bedding plains and cleavage. He also had a capacity for translating local field observations into a broader regional context. This ability was early indicated when in 1822 he set about deciphering the dramatic and geologically complex rocks of the Lake District. It was in that year he first met William Wordsworth with whom he developed a warm friendship. They carried out many joint excursions into the Cumbrian Mountains. Sedgwick's *Letters on the Geology of the Lake District*, possibly his most well-known and widely read composition (Speakman 1982: 64), was later published along with Wordsworth's *Guide to the Lakes* in John Hudson's *Complete Guide to the Lakes* in 1842.

Sedgwick took an early interest in geological questions associated with lithology and stratigraphy. He was particularly influenced by the work of William Conybeare, one of the founders of systematic stratigraphy. In 1822, William Conybeare and William Phillips published their *Outlines of the Geology of England and Wales*, a handbook that summarised the stratigraphy of England, as it was then understood — from the recent unconsolidated sediments in eastern England to the base of the Old Red Sandstone in the west. This book helped lay down the foundations of English stratigraphical geology and influenced the direction and content of both Sedgwick's and Murchison's subsequent research.

Abraham Werner had earlier, by the 1790s, firmly established the concept of geological succession as the basis for the science of geology as it was then conceived. Werner subdivided the geological column into three principal sequences or 'formations', i.e., Primitive (or Primary), Secondary and Tertiary. He later added a fourth subdivision, the 'Transition' sequence, to denote an obscure and somewhat ambiguous series of rocks between the apparently unfossiliferous Primary rocks and the Secondary rocks which were usually layered and fossiliferous. The Primary, Secondary and Tertiary rocks in general seemed relatively straightforward and accessible for study, but the Transition rocks were somewhat of a mystery. The Transition rocks were usually layered or stratified but generally highly deformed, and even though fossils were known to be present they did not appear to be in great abundance. The opportunity for unravelling the true nature of this as yet poorly elucidated sequence beckoned for any aspiring ambitious geologist. There was the added attraction that it was then assumed that somewhere in the Transition sequence

the exact point at which life began might be discovered. Sedgwick and Murchison decided to take up the challenge by attempting to decipher the Transition rocks in southwest Britain.

Roderick Impey Murchison

Murchison, like Sedgwick, became a leading figure in nineteenth century geology (Stafford 1989), and eventually eclipsed Sedgwick in status. His earliest most important influence was William Buckland, professor of geology at Oxford University. Murchison was seven years Sedgwick's junior and actively cultivated a relationship with him; he benefited considerably from Sedgwick's geological knowledge and experience. Highly focussed and intensely ambitious. Murchison eventually outgrew his mentors to become one of the most influential scientists of modern times. He achieved this by hard work and a strategic research campaign — and also by securing membership and leadership of important scientific societies such as the Geological Society of London that he joined in 1824 and served as president from 1831 to 1834 and again from 1841 to 1843. He was a co-founder of the Royal Geographical Society and was its president for many years, enabling him to become a principle player in colonial science and exploration (see Stafford 1989). This dominance was further enhanced when he became director general of the Geological Survey of Great Britain in 1855 following the death of De la Beche. Murchison's influence eventually extended around the globe — including not only the British Empire but also Europe and North America.

Collaboration

Murchison's collaboration with Sedgwick began in the latter half of the 1820s; they conducted field trips to Scotland (1827) and the French Alps (1829) and published lengthy memoirs in the *Transactions* of the Geological Society. In 1831 they turned their attention to the relatively unknown Transition rocks of southwest England and Wales. The Transition rocks mainly consisted of thick confusing sequences of slate and the coarse dark sandstone known as greywacke. Greywacke is grey-coloured, poorly sorted sandstone ('dirty sandstone') consisting of quartz and feldspar grains and broken rock fragments mixed with substantial amounts of clay particles. Most of these Transition rocks were folded, faulted and altered.

To make sense of the Transition sequence was potentially a huge task so they decided upon a division of labour. Sedgwick would tackle the older primary and apparently lower Transition slaty rocks of North Wales. Murchison on the other hand decided on an approach from Western England into Wales from the southeast and would tackle the upper Transition sequences which were less disturbed and, as he discovered, more fossiliferous. For several field seasons they systematically devoted themselves to the task. Working cooperatively, but separately, they were soon satisfied that they were studying two different but contiguous geological 'systems'. By 1834 they felt that each had identified and interpreted the major structural, lithological and palaeontological features of their respective regions. So, in that year they spent four weeks together on their first, and what turned out to be, their only, joint field trip on the Transition rocks, in order to work out how the two systems meshed together and precisely where the common boundary might be.

Although the 1834 field trip was comparatively brief and a few issues remained unresolved, the two co-workers were confident that they had done enough work to clearly delineate two discreet geological systems and the joint boundary between them. Consequently, in 1835 Murchison designated his section as the 'Silurian' system, after an ancient British tribe that had inhabited the area. Sedgwick followed soon after with the name 'Cambrian' for the lower section after the Roman name for Wales. In August 1835 Murchison and Sedgwick presented a joint paper before the British Association for the Advancement of Science titled *On the Silurian and Cambrian Systems, exhibiting the order in which the older sedimentary strata succeed each other in England and Wales.* Both geologists were justly proud of their achievement. They were aware that their success in unravelling the structure and order of succession for the Lower Palaeozoic rocks in Britain would likely have global ramifications.

Interlude: The Fossil Plants of Devon

Even as Murchison and Sedgwick presented their findings on the Transition rocks in 1835, however, a complication had already arisen which loomed as a potential threat to their proposed classification. Just prior to their announcement of the establishment of

the Silurian and Cambrian systems, Henry De la Beche, in December 1834, reported that he had discovered fossil coal plants in Devon, supposedly of Carboniferous age, in the greywacke rocks (Rudwick 1985: 93). Sedgwick and Murchison were alarmed by De la Beche's report because it appeared to contradict their claims that the greywacke strata they themselves were studying were more ancient, and below the Carboniferous, with probably different plant types, if any at all. They felt sure that De la Beche was wrong and in 1836 they went out to investigate the area for themselves. They were able to establish that the coal bearing rocks were indeed above the greywacke and almost certainly did belong to the Carboniferous. However, the strata of rocks just below the coal bearing ones were intriguing and captured their attention because they appeared a bit different from anything else they had examined before. Because of their lithological form these rocks were initially thought to be Cambrian, but unlike Sedgwick's strata in North Wales which were relatively deficient in fossils, the rocks in Devon included many limestone beds and contained numerous fossils that had no apparent affinities with the Cambrian. Likewise, Murchison was reasonably sure they were not Silurian although there did appear to be some similarities between some elements of the two faunas. Another feature of these rocks was that the Old Red Sandstone was absent, whereas to the north, in Wales and the adjacent counties in England, it was present — in some places thousands of feet thick — and occupied a position below the Carboniferous but above the Silurian.

The controversy simmered for several years but in 1837 moved towards resolution following the suggestion by William Lonsdale — who was an expert on corals from the Carboniferous (or 'Mountain') limestone and had also worked on the Silurian corals — that in his opinion the disputed fauna was intermediate in character between the Carboniferous and the Silurian. In effect, the disputed fauna came from rocks that were apparently a marine sequence equivalent to the non-marine Old Red Sandstone in other areas of England and Scotland. At first there was some hesitation by Sedgwick and Murchison in accepting this explanation but after further study, including a field trip to Germany and Belgium in 1839, they came to the view that what they were dealing with was a distinct fauna in its own right and gave it the name 'Devonian'. This verdict was notable because it rested primarily on the fossil evidence rather than the lithology. This was the first time that priority had been given to fossils in defining a major new geological system.

Publication of The Silurian System

Murchison, in particular, was determined to defend and promote his and Sedgwick's interpretation of the Transition rocks, or at least Murchison's version of it. In his introduction to *The Silurian System* (1839: 6) Murchison indicates that he initially intended to publish his results as a memoir in the *Transactions* of the Geological Society (Thackray 1978: 63; Bassett 1991: 20). As early as 1834 arrangements were made with the London publisher John Murray for the production of a separate treatise. A prospectus was issued and subscribers were sought. It took until 1839, however, before the project could be brought to completion. The result was a massive work, possibly three times the size originally planned (Thackray 1978: 64). *The Silurian System* was one of the most significant geological publications of the nineteenth century. By any measure it was an outstanding production. It was a hefty two-volume work, 820 pages in length, with a large folding accompanying map bound separately. It was also liberally illustrated with 112 wood engravings in the text and 14 scenic plates, three of which were hand coloured. In addition, in the second volume titled "Part II. Organic Remains" there was included 31 plates of fossils plus 9 hand-coloured fold-out copper plate engravings of geological sections. The palaeontological volume was essentially an edited work with contributions from J. de C. Sowerby and John Salter (shells, including the molluscs and brachiopods), Louis Agassiz (fish), William Lonsdale (corals) and Murchison himself with Charles Stokes (trilobites). Other minor contributors included John Phillips (encrinites), W.S. Macleay (annelids), Milne Edwards ('nondescripts'), W.J. Broderip (bivalves), and C. Koenig and H.H. Beck (graptolites).

The text was comprehensive, authoritative and accessible — but most of all it was a rationale for Murchison's Silurian system and a testament to his rise to dominance in world geology and palaeontology. Murchison's Silurian system with its characteristic invertebrate fauna rapidly gained acceptance in Europe and North America. The book was dedicated to Sedgwick but in hindsight it was a dedication that probably became more of an embarrassment to Sedgwick than a tribute — particularly as Sedgwick failed to produce a similar magnum opus despite repeated promises to do so.

The publication of *The Silurian System* made public for the first time differences of interpretation in exactly where the boundary lay between the Cambrian and Silurian. Sedgwick was surprised to find that certain areas that he and Murchison had formerly agreed were Cambrian were now claimed by Murchison to be Silurian. Initial polite disagreement over these relatively minor regions eventually escalated into one of the major geological disputes of the nineteenth century — mainly because Murchison in his publications progressively annexed more and more of Sedgwick's Cambrian strata until little remained. To employ a military metaphor (which Murchison loved to do), we could say that what began as a border skirmish ended up as open warfare and a strategic grab for territory.

The Cambrian–Silurian Conflict

Privately and publicly, argument and counter-argument took place in this protracted and rather complicated debate over the next two decades. Murchison, however, steadily and inexorably gained the ascendancy in the debate. Early in his geological career Murchison was impressed by the importance and efficacy of fossils in determining the age and order of the rock strata (although in this he had to rely on the skills of palaeontologists such as Lonsdale, Phillips, Sowerby and Salter rather than on his own determinations). While he recognised that lithology was important, Murchison over the years became increasingly conscious of the potential of fossils to define uniquely and correlate different rock strata. His confidence was strengthened when he discovered that with a bit of dedicated fieldwork Silurian rocks could be found that contained a recognisable and distinct fauna. Sedgwick, by contrast, like the majority of geologists, such as Aveline, Ramsay, Selwyn and others of the Geological Survey, believed in the primacy of lithology as a basis for identifying and delimiting the stratigraphical sequence. Sedgwick viewed fossils as a secondary tool, and certainly useful when other methods are unavailable, but believed that they should not be relied upon as the primary instrument in stratigraphical analysis. In his 1831 presidential address to the Geological Society of London he pointed out:

> "Organic remains often help us to associate disconnected base lines. They also help us subdivide the successive deposits of an epoch, in areas where all other means fail; and in speculating on the former condition of the earth they are invaluable; but they can in no instance supercede the necessity of study in detail of the structure and superposition of the great mineral masses covering the surface of the globe" (Sedgwick 1831; Speakman 1982: 78).

Even though Sedgwick regularly collected fossils on his field trips he admitted that although he knew many of them "by sight" he did not always know them by name (Speakman 1982: 78). Many of the fossils he collected remained unpacked and unsorted in the Cambridge Woodwardian Museum. Sedgwick was also at a disadvantage in the debate in that he was unable to establish an unequivocal distinct fauna in the apparently less fossiliferous Cambrian rocks. Instead he emphasised the immense thickness of the Cambrian strata. But as Murchison later declared: "…was the Cambrian system ever so defined, that a competent observer going into uninvestigated country could determine whether it existed there?" (Murchison 1852: 176; Berry 1968: 87). Murchison did indeed have a point; while geologists could positively identify his characteristic Silurian fossils anywhere they occurred around the globe, the best that could be said of Sedgwick's system was that it was a local entity that may or may not have implications outside his study area in Wales. Murchison was free to claim that Sedgwick's system was merely an earlier extension of the Silurian, and he did just that. By 1842 Murchison was asserting that on the basis of the evidence gathered up until that time it now appeared that Sedgwick's Upper Cambrian fossils were identical with his own Lower Silurian fauna. Only a small section of unfossiliferous rocks remained of Sedgwick's original Cambrian.

Sedgwick argued long and hard over the ensuing years in order to save his system. He carried out more fieldwork, he examined new areas and re-examined old ones, he put forward a number of new schemes, he invented new terminology and he was even willing to drop the name Cambrian altogether; however at this stage of the dispute he made limited progress in winning converts and convincing others of the merits of his ideas. As a result of Murchison placing more and more emphasis on fossil evidence to justify his system Sedgwick was forced to take the palaeontological aspect of the work much more seriously.

In 1842 he employed a young palaeontologist, John Salter, part-time, to help process the now vast collection of fossils he had accumulated over the years. Salter also accompanied him on a number of

fieldtrips to North Wales collecting fossils in an attempt to clarify the palaeontology and possibly even discover a discreet but simpler fauna than the Silurian, although by this time Sedgwick had virtually given up any hope of finding enough distinctive species (Secord 1986: 116). Even though they discovered some new fossils, there were not enough to constitute a system distinct from the Silurian. The remainder of the fossils collected were Lower Silurian types, which by now Sedgwick had come to expect. Salter made a promising start on cataloguing the Woodwardian Museum collection but soon left for full-time employment at the Geological Survey of Great Britain. This again left Sedgwick with the need for the services of a palaeontologist. The job was offered to a grateful Frederick McCoy who was relieved to be able to remove himself from the difficult circumstances he found himself in under Thomas Oldham's supervision in Ireland. McCoy's task was to complete the work that had been started by Salter.

McCoy and Murchison's 'Caradoc Sandstone'

McCoy, like Salter before him, arrived at a critical stage in the Cambrian–Silurian debate. McCoy conscientiously applied himself to the task of processing and determining the fossils in the Woodwardian Museum but also inevitably became involved in issues related to the disagreement between Sedgwick and Murchison. It should be noted that by the time of McCoy's arrival at Cambridge in 1846 it was not just Murchison and Sedgwick who had examined the Transition strata in question. By 1841 professional geologists of the official Geological Survey of Great Britain, who had just completed mapping of the coalfields of South Wales, began mapping in the area under dispute. John Phillips, one of the Survey's palaeontologists, reported that, in the Caradoc formation which was located towards the bottom of Murchison's Upper Silurian system, there were occasional anomalies, particularly in the Malvern Hills, in which Lower Silurian fossils would be found mixed with Upper Silurian (Phillips 1848). Everyone involved in the debate, including Sedgwick, believed that the Caradoc Sandstone was a coherent set of so-called "passage beds" positioned between the Silurian and the Cambrian which therefore could feasibly contain an intermediate or a mixed fauna. McCoy, however, probably alerted by the Malvern Hills anomalies reported by Phillips (Bassett 1991: 31) began to suspect that possibly there were two different faunas involved, in deceptively conformable beds, but which appeared to be one lithological unit. Consequently McCoy, in the summer of 1852 was moved to conduct a review of the Caradoc faunas.

On examination of Caradoc fossils from a number of different localities McCoy found that they did separate out into two quite different groups — from some localities the Caradoc fossils had affinities with the Upper Silurian, from other localities the Caradoc fossils had affinities with the Lower Silurian (Murchison's Lower Silurian being roughly equivalent to Sedgwick's Cambrian). This strongly suggested the presence of a previously undetected unconformity within the Caradoc Sandstone. If McCoy was correct, then Sedgwick finally had a decisive and convincing way of splitting the Transition strata into two natural systems. Sedgwick was not willing to publicly announce these findings until he had confirmed them by examination of the Caradoc rocks in the field. In mid 1852 McCoy accompanied Sedgwick on a brief, rain-interrupted field trip which only allowed them to examine systematically the rock sections at May Hill and the Malverns, but that was enough to confirm McCoy's findings and vindicate Sedgwick's claims for a separate Cambrian system.

In November 1852 Sedgwick triumphantly presented his results in a paper to the Geological Society. Sedgwick asserted that he was able to justify subdividing the former Caradoc formation into two new groups; the upper part he named the May Hill Sandstone, the base of which Sedgwick designated as the base of the Silurian; for the lower part he retained the name Caradoc, this he designated as the top of the Cambrian. The fossil gap between the Cambrian and the Silurian on this evidence was much greater than the break between the Silurian and Devonian that Murchison had so strongly advocated; in fact, it proved to be one of the larger breaks in the whole of the fossil record. Sedgwick's explanation also correlated well with similar findings in Palaeozoic strata in central Europe and North America.

The reaction to Sedgwick's presentation by the members of the Geological Society was one of either stunned disbelief or grave scepticism. At first they could not accept that the professional geologists of the Geological Survey would not have realised or noticed that such a large geological and palaeontological divide existed between the two proposed systems. However, further work revealed that

this was indeed the case. McCoy, incidentally, had also been present at the meeting in which Sedgwick presented his findings but interestingly he was not a co-author of the paper. Edward Forbes initially believed that McCoy had "cooked" the fossil evidence in order to please Sedgwick (Secord 1986: 246). The Survey team were in an embarrassing position — in their detailed examination and mapping of the relevant strata they had not noticed any discontinuity in the rock sequence or in the fossil record (apart from Phillips' report of minor anomalies). They were forced back out in the field to re-examine critical sections and duly discovered previously unnoticed unconformities.

The Survey team tried to play down the significance of Sedgwick and McCoy's research and even suggested that they had only repeated work that had already been carried out by Phillips and others. But of course there is a huge difference in noticing and recording a variation or anomaly and in understanding its significance. Over the next few years Aveline, Salter and Ramsay of the Survey team, as well as Sedgwick and McCoy, carried out numerous field trips into Wales examining rock sections, clarifying the identity and range of key groups of fossils, and revising and redrawing critical boundaries on their geological maps. It does seem somewhat ironic that McCoy, who is sometimes disparaged for the quality and quantity of his fieldwork, happened to participate in fieldwork — although admittedly in the presence of Sedgwick, one of the most capable field geologists of his era — that led to the eventual resolution of one of the most intractable and historically significant disputes of the formative period of stratigraphical palaeontology.

Murchison, however, was not prepared to concede that he had been in error; by this time he had gained international acclaim for his work on the Silurian. Murchison evidently felt that the stratigraphical model that he had so assiduously and so laboriously constructed, now almost self-evident, would be in danger of being ruined, along with his scientific reputation, if he yielded to Sedgwick's revised Cambrian. Independently wealthy, Murchison was also in a powerful position institutionally, and even more so after he became Director of the Geological Survey on the death of De la Beche in 1855. In contrast to Sedgwick, his career and reputation had gone from strength to strength. He was knighted in 1846. In 1841, on his second expedition to Russia, he succeeded in making another important contribution to world geology. In the district of Perm located on the Western flank of the Ural Mountains he identified a thick, relatively undisturbed sequence of rocks overlying the Carboniferous that he designated the 'Permian'; another significant geological system was thus identified and defined. In 1845 he published a second major work *Geology of Russia in Europe and the Ural Mountains* (co-authored with de Verneuil and von Keyserling).

Sedgwick, sadly, was never able to complete his proposed opus on the Transition strata intended as a companion volume to Conybeare and Phillips' *Outlines*. Sedgwick became increasingly embittered at Murchison's unwillingness to recant, and isolated himself from the Geological Society. This played into Murchison's hands and there were suggestions by members of the Geological Survey that Sedgwick was a zealot and probably going senile or insane.

McCoy's reputation, too, suffered by association. Edward Forbes satirically depicted Sedgwick as Don Quixote, and McCoy as Sancho Panza (Secord 1986: 267). While this representation of Sedgwick displays a certain respect for his moral integrity, it strongly suggests he is fighting for a hopeless cause and perhaps a little obsessed and a little mad. McCoy, by implication, is portrayed as a blind, loyal subordinate who would do anything to please his master. One partial consequence of the factionalism in this dispute and the defence of entrenched positions is that McCoy has never received due recognition for his contribution to resolution of the debate or for his wider contributions to palaeontology and biostratigraphy. Murchison used his influence as head of the Geological Survey, and as a member of the Geological Society and other organisations, to control the terms and direction of the debate and to prevent any changes in nomenclature or in the details of the standard geological maps of which he did not approve. For ambitious younger geologists and palaeontologists jobs were scarce and Murchison's patronage and approval were essential if they were to have any real chance of obtaining a desired position or gaining promotion. In this respect McCoy was no exception.

As the debate dragged on McCoy tried to distance himself publicly somewhat from Sedgwick although privately he remained a steadfast supporter. He tried to indicate to Murchison that he was 'just doing his job' objectively without prejudice or personal preference. In a telling letter to Murchison in June 1852, McCoy disingenuously declared his impartiality in the debate at the very time he was

urging Sedgwick to re-examine and reassess the Caradoc Sandstone sections:

> "I hope that you and Professor Sedgwick have long before this settled to your mutual satisfaction the bounds of your grounds? I feared I should have come in for some knocks, although I have never intruded myself into the discussion but confined myself to identifying the fossils to the best of my ability and registering them faithfully. A smack from you would probably ruin my prospects, and I think undesirably — but I believe you spare the weak in as marked a manner as you grapple with the strong." (McCoy to Murchison, 12 June 1852, in Craig 1971: 494; Secord 1986: 271)

Murchison was aware that McCoy was an able and self-assured palaeontologist, and even a dangerous one while he was working in league with Sedgwick. Hence, it suited Murchison to give McCoy a favourable reference for the Foundation chair of Natural Science at the newly established University of Melbourne. Whether Murchison's testimonial was given because he genuinely believed that McCoy deserved the position based on merit, or simply because he wanted to get him out of the way, or both, it is difficult to say, but it did have the dual effect of removing support for and further isolating Sedgwick and removing McCoy from the mainstream activities in Great Britain. In 1854 McCoy applied for the Melbourne chair and was successful against a strong field of candidates. In early October of that year he set sail from England for Australia in the clipper *Champion of the Seas* (Wilkinson 1996: 54) and disembarked in Melbourne where he would spend most of the rest of his working life.

In the years that followed, local and international support for the Cambrian grew, but Murchison died in 1871 still opposing any change in nomenclature. The debate was effectively settled with the inclusion of the Ordovician system by Lapworth in 1879 which was inserted as a kind of no-man's land between the Cambrian and Silurian systems although, remarkably, even though the case for a new system based on the fossil evidence was compelling it took until 1960 for the Ordovician to gain full international approval (Secord 1986: 310). The new Ordovician encompassed Sedgwick's Upper Cambrian and Murchison's Lower Silurian, but one can speculate with confidence that both protagonists probably would not have been at all enamoured with Lapworth's partial appropriation of their respective geological territories.

McCoy in Melbourne

When McCoy arrived in the Colony of Victoria in December 1854 as one of the first four professors at the University of Melbourne he was still only in his early thirties and already an accomplished palaeontologist. Not only was he thoroughly familiar with Irish and British fossils but had also had some experience with Australian material. In Great Britain he had worked on Australian fossils collected by the Reverend W.B. Clarke and sent to Sedgwick at Cambridge. In 1847, he published a paper based on this work titled "On the fossil botany and zoology of the rocks associated with the coal of Australia" in the *Annals and Magazine of Natural History*. This familiarity with Australian fossils was possibly one of the factors that enticed him into immigrating to Australia. Soon after his arrival in Victoria as Professor of Natural Science, McCoy set about grappling with issues connected with the local palaeontology and stratigraphy and (with Murchison's endorsement) was appointed Palaeontologist to the Geological Survey of Victoria in 1856. He moved quickly in taking over the Colony's fledgling natural history museum and despite some spirited public opposition moved it from its city location to the grounds of the University of Melbourne (Pescott 1954; Wilkinson 1996; Rasmussen 2001). Overcoming many obstacles, including numerous bureaucratic disagreements, political disputes, and ongoing funding shortfalls, he resolutely proceeded to build the National Museum into a world-class institution. He was appointed Director in 1858.

Australian Stratigraphy Before 1850

Prior to McCoy's arrival in Australia in 1854 there had been no resident skilled palaeontologist. Geological observations had been carried out by many of the early explorers and naturalists such as Mitchell, Leichhardt, Strzelecki, Oxley, Grey, Cunningham, King, Gregory, Stokes, Sturt, Eyre, Darwin, Dana, Jukes, Clarke, Stutchbury and others. Some of these geological observations were of a high standard, e.g., those of Leichhardt (1847) and Strzelecki (1845); other observations had been more cursory and less reliable but nevertheless still interesting and suggestive. Visitors from overseas such as Darwin and Jukes made valuable observations and determinations, as did James Dana from North America who collected fossils and worked on them.

Fig. 2. Photograph of Frederick McCoy, c. 1870, seated. Johnstone, O'Shannessy & Co., photographers. H29553. La Trobe Picture Collection, State Library of Victoria.

Generally though, in order to obtain reliable fossil determinations, specimens had to be sent overseas to Britain and Europe for identification by expert palaeontologists such as Lonsdale, Morris, Owen, Sowerby, de Verneuil, de Koninck, d'Orbigny and, indeed, McCoy himself. The first steps in elucidating the stratigraphy of Australian rocks were being made but much of this work remained unconfirmed and uncertain.

Although it was well established that in a mineralogical and lithological sense rocks all over the planet were broadly comparable the old Wernerian notion of universal formations had been superseded. Grand global geological theories were now being treated with suspicion, and in keeping with prevailing scientific method most geologists adopted, or at least, subscribed to, a strict empirical and inductive approach. There were conflicting notions of what the geological evidence signified and how the stratigraphy of Australia fitted into the overall picture. In an interesting paper published in the *Tasmanian Journal of Natural Science* in 1843, the English geologist Joseph Beete Jukes, who spent from 1842 to 1846 in Australia waters as naturalist on board H.M.S. *Fly*, cautioned against drawing any hasty and premature conclusions when dealing with non-European strata:

> "The European geologist, in approaching distant countries, must loose his hold of much of his previously acquired knowledge; dismiss from his mind all the arbitrary and minute divisions to which he has been hitherto accustomed, and hold them at bay until he see whether or not they be applicable to the things he is now studying. He must at once fall back on the general principles on which all geological classification ought to be founded; and, guided solely by these, separate the rocks he meets with into those portions and divisions only which naturally belong to them. When each large portion of the globe shall have been examined, and its constituent portions classified and arranged in this manner, geologists will be able to compare them one with the other, to establish well-defined bases, and make out the corresponding terms in each series, and tabulate the whole according to their united result." (Jukes 1843: 4–5)

In 1850 Jukes published a small monograph *A Sketch of the Physical Structure of Australia, so far as it is at present known* in which he summarised his conclusions concerning the geology of Australia based on his own first-hand observations combined with information from the published reports and books of other explorers and naturalists, some of whom he met personally such as Mitchell, Strzelecki and Sturt. This memoir was the first brief but comprehensive summary of Australian stratigraphy and was a valuable synopsis of isolated geological observations from a variety of sources. Included in his book was a coloured geological map of Australia which attempted to encompass the continent as a whole, although of necessity much of the unexplored interior remained a blank. Although he discussed the Australian palaeozoic rocks in general, Jukes was reluctant to subdivide them any further based on the then current knowledge:

> "... I should for the present hold that the rocks of Australia now under consideration simply as palaeozoic, and only assert that their age was included within that of our Silurian, Devonian, and Carboniferous periods." (Jukes 1850: 22)

Jukes attempted to locate Australian geology in a broader international context and tentatively noted many similarities between European and Australian geology and geomorphology but was also intrigued by the apparent differences. He was impressed by the "simplicity and uniformity of the geology when looked at on the great scale" (Jukes 1850: 79). As Vallance (1975: 22) explains, the early Australian explorers "found a continent whose physical features differed utterly from those of Europe; Instead of a great median mountain axis in Australia there were low arid plains, the mountains of Australia followed the east coast." Jukes (1850: 1) conceded that it was difficult for geologists "accustomed only to the full, varied, and complex structure of Europe" to come to terms with the very different situation in Australia. To an external observer Australian geology appeared deceptively uncomplicated. He observed that,

> "Australia especially seems the very land of uniformity and monotony, the same dull and sombre vegetation, the same marsupial type of animals, spread over the whole land from the gloomy capes of the south coast of Tasmania, and the stormy Leeuwin, to the cloudless and burning skies of Torres Straits and Port Essington." (Jukes 1850: 2)

The Missing Mesozoic

Jukes, like many other observers before and after him, was impressed by the idea that Australia was a

land of anomalies. The anomalous geology and geomorphology seemingly matched the similarly anomalous flora and fauna. According to Jukes, a number of geologists had,

> "been struck with the entire absence of all "secondary" formations in Australia, and with analogies between the fossil flora and fauna of our European oolitic series, and those now found living in Australia and Australian seas."

Ever since the time of Lamarck and the discovery of the bivalve *Trigonia*, found alive in Australian waters but extinct in Europe since the Mesozoic, and of various marsupials and plants which were long since extinct in Europe, there was a popular notion that Australia was 'the land that time forgot'. The rocks, the animals, the plants and even the indigenous human population were all, in comparison with Europe, very ancient. Jukes (1850: 80) noted the "total absence of any rocks of an age intermediate between the palaeozoic and tertiary, so far as is at present known or appears probable". Further on (Jukes 1850: 89) he reiterated the same point, stating: "Above the palaeozoic series there is an absolute gap, a total deficiency of all other stratified rocks, whatsoever…" except for a much more recent tertiary formation, and speculated (p. 90) that,

> "We have therefore two reasons; namely, the absence of marine formations of the oolitic age, and the possible descent of some of the animals and plants from those that lived at that period; for supposing that after the deposition of palaeozoic rocks, what is now Australia was raised into dry land, and that some portion or portions of it at all events have ever since remained above the level of the sea."

This would account for the missing Mesozoic in Australia and the preservation of organic forms which long ago had become extinct in Europe.

Jukes became a highly respected geologist in Great Britain and his views carried considerable weight. On his return to England from Australia he joined the Geological Survey of Great Britain and proved himself to be a talented field geologist working in North Wales and South Staffordshire alongside other staff members such as Andrew Ramsay, William Aveline, Alfred Selwyn and palaeontologist John Salter. In 1850 he was appointed as Director of the Geological Survey of Ireland where he served with distinction until his premature death in 1869. He wrote many papers and a number of text books which presented his views to other geologists, students and the general public.

Selwyn, McCoy and the Geological Survey of Victoria

In 1852, following the discovery of gold the previous year, and two years before McCoy's arrival, the Victorian government established a Geological Survey. The Colony was extremely fortunate in gaining the services of Alfred Selwyn as Government Geologist and later Director of the Geological Survey. It would be difficult to imagine a more appropriate choice. Prior to his appointment Selwyn had considerable experience mapping the palaeozoic rocks of North Wales which were apparently a direct analogue of the gold bearing slates of Victoria. Selwyn's appointment (1852–1869) marked the commencement of systematic geological mapping in Australia. Selwyn and his staff surveyed large tracts of the Victorian countryside and after his arrival McCoy did the palaeontological determinations necessary to determine the relative ages of the strata.

It was a highly productive collaboration. Between them Selwyn and McCoy determined the line of demarcation between the Upper Silurian (now the Silurian proper) and the Lower Silurian (now the Ordovician and Cambrian) and then steadily worked their way up the geological column. Selwyn having worked at the Geological Survey of Great Britain preferred Murchison's terminology of 'Lower Silurian' for the lower strata while McCoy having been a protégé of Sedgwick preferred to use the term 'Cambrian'. Ralph Tate (1894: 490) who a gave a paper titled 'Century of Geological Progress' for his presidential address for the fifth meeting of ANZAAS in Adelaide in 1893 remarked on this milestone in Australian geology, as follows:

> "Up to 1853 the geology of Victoria was almost a blank. What little was then known of it was due to Mitchell, Strzelecki, and Jukes, but that little was for the most part either misread, or too indefinite to be available in the future. Thanks to the ability and zeal of Mr. Selwyn and the members of his staff, aided by the palaeontological determinations of Professor McCoy, the geological structure of Victoria was rapidly unfolded, and large tracts of country were geologically surveyed in detail…."

Further on in his address, under the subheading 'Summary of Discoveries and Original Researches', Tate continued:

> "1858. Selwyn (Quart. Journ. Geol. Soc., vol. xiv., p. 533) drew the line of demarcation between the auriferous graptolite slates [Ordovi-

cian and Cambrian] and Upper Silurian [Silurian], which McCoy had shown to have faunas characteristic of the corresponding series in Europe, and thus established the fact of the specific identity of the two faunas over the whole world."

McCoy and the Global Geological Column

In 1861 McCoy published in the Victorian Exhibition Catalogue the first summary of the zoology and palaeontology of Victoria (McCoy 1861). This paper was reprinted in 1862 in the *Annals and Magazine of Natural History*. In the paper McCoy argued that based on palaeontological evidence the geological column in Australia in general conformed to that of Great Britain, Europe and North America. For the first time it was could be stated unequivocally that the rock sequences in the Southern Hemisphere, despite some provincialism, correlated well with those of the Northern Hemisphere. In other words, the geological column as deciphered in Great Britain was almost certainly a global phenomenon. This relationship held especially for the Lower Palaeozoic but McCoy believed it was generally true for the whole geological column.

McCoy declared that "... from the great quantity of fossils which I have lately examined as Palaeontologist to the Geological Survey of Victoria; and from evidence of this kind I can offer a sketch of the ancient successive changes of organic life in this country" (McCoy 1861: 160). He proceeded to discuss each of the major geological periods in turn. Beginning with the [Lower] Palaeozoic he asserted that:

> The Azoic [Precambrian] rocks, I can now state, were succeeded in Victoria, exactly as in Wales, Sweden, North America, and other parts of the world in the northern hemisphere, by a series of rocks enclosing fossil remains of the well-known genera and even specific types of animal life characterizing those most ancient fossiliferous strata termed Lower Silurian by Sir R. Murchison, and Cambrian by Professor Sedgwick (McCoy 1861: 160).

McCoy then went on to discuss further correspondences between Australian biostratigraphy and Northern Hemisphere biostratigraphy for the rest of the geological column, i.e., the Upper Palaeozoic, Mesozoic, Tertiary and Recent periods. McCoy demonstrated striking global similarities in the fossil record across much of the geological column. In doing this, however, McCoy overstated the similarities, particularly for the upper part of the column, and it was probably this conviction that prevented him appreciating important differences which later led to the development of the concept of Gondwana, the great southern supercontinent.

At the time of the 1861 publication McCoy had already confirmed presence of the Jurassic (or "Oolitic") based on marine fossils from Queensland in 1861 and on the flora of the Bellarine and Cape Patterson coal beds of Victoria in 1860, but evidence for the Cretaceous period had not been positively confirmed in Australia. However, in 1865 McCoy was able "... to announce for the first time with certainty the existence of the Cretaceous formations in Australia." (McCoy 1865: 333) based on fossils sent to him from Queensland that included bivalves, ammonites and ichthyosaur vertebrae. Similarly, although fossils from the Devonian period in Australia had been earlier identified by Stutchbury for example, there was some doubt about the validity of this interpretation. In an essay prepared for the 1866–67 Melbourne Intercolonial Exhibition (McCoy 1867a) and reprinted in the *Annals and Magazine of Natural History* in 1867 he claimed that he had definitely confirmed the presence of the Devonian in Australia based on marine fossils from Buchan in Gippsland. McCoy declared:

> "It is with great pleasure I announce the fact of my having been able satisfactorily to determine the existence of this formation also in Australia, the limestone of Buchan in Gippsland containing characteristic corals, Placodermatous fish, and abundance of the *Spirifera laevicostata*, perfectly identical with specimens from the European Devonian Limestones of the Eifel" (McCoy 1867a: 327 (21); 1867b: 198).

For McCoy, the confirmation of these formations filled in the remaining major gaps in the geological record for Australia and demonstrated that there was an almost complete correspondence between northern hemisphere and southern hemisphere stratigraphy.

A shortened version of this paper was also made available for a North American audience and published in *The American Journal of Science and Arts* edited by Benjamin Silliman and James Dana (McCoy 1867c: 279–282). In this version, as in the original paper, when discussing the Cambrian he reiterated: "... we have in these formations the most extraordinary proof of the unexpected fact which I announced on a former occasion, that there was in the Cambrian or Lower Silurian period a nearly

complete specific uniformity of the marine faunas, not only over the whole northern hemisphere, but across the tropics, extending to this remote temperate latitude of the southern hemisphere" (McCoy 1867c: 280).

In his conclusion to the above papers McCoy reminded the reader that he had been instrumental in contributing to the solution of the Cambrian–Silurian debate and that exactly the same geological situation prevailed in Australia as it did in Great Britain. McCoy concluded:

> "I can scarcely close … without drawing attention to the curious confirmation offered in Victorian geology of the view of Professor Sedgwick and myself, that there was a real systematic line of division between the Upper Silurian and the Cambrian and Lower Silurian, at the base of the Mayhill Sandstone and over the Caradoc Sandstone — the Mayhill Sandstone, which we first defined and demonstrated to have Upper-Silurian fossils only, and the true Caradoc Sandstone full exclusively of Lower-Silurian or Cambrian types, — the previous confusion between these two sandstones, from the erroneous mingling of their fossils in collections, having given Sir Roderick Murchison the erroneous impression that his Upper and Lower Silurian groups of fossils … could not be separated palaeontologically….The Mayhill Sandstone was one of the first formations I recognized, on landing near Melbourne, with the usual Upper-Silurian fossils; and it is now found here, as in Wales, to be slightly unconformable to the Cambrian or Lower Silurian, forming the obvious base of the former and totally distinct [in fossils] from the latter" (McCoy 1867a: 330 (24); 1867b: 201–202; 1867c: 282).

Of course it should be acknowledged that McCoy's claims for the correlation of the Australian stratigraphy with Northern Hemisphere stratigraphy were based on not only his own work but also built on the earlier work of other geologists (e.g., see Vallance 1975; Branagan 1998). Nevertheless, it was McCoy who was the first to publish a synthesis and indicate that he was the first to fully grasp the broader implications of the local geology, palaeontology and stratigraphy and place it in a global context. Few people could have been better prepared than McCoy to appreciate the Australian stratigraphy and be able to relate it back to the British and European and American situation. He had made a significant contribution to systematically sorting, naming and describing the Palaeozoic fossils of Ireland and Britain, and had played a key role in the debate between Adam Sedgwick and Roderick Murchison on where to draw the boundary between the Cambrian and Silurian periods. At the time of his arrival in Australia he was one of the world's most experienced palaeontologists, and as Adam Sedgwick's assistant, he had played a subordinate but

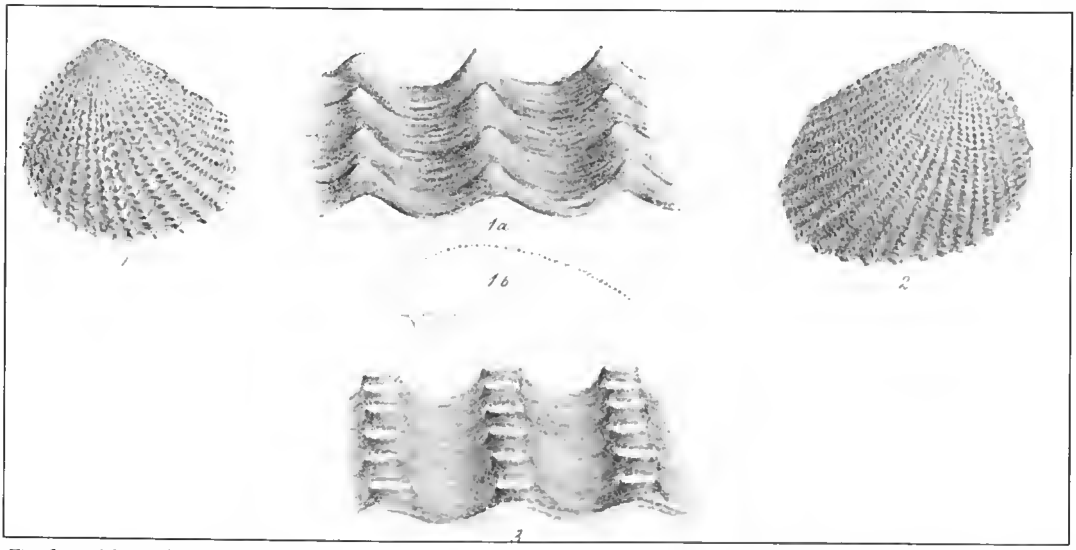

Fig. 3. Illustration of the bivalve *Trigonia acuticostata* McCoy [now *Neotrigonia acuticostata*] comparing it to the previously known *Trigonia Lamarcki* showing the acute ribs and tubercles of *T acuticostata* in contrast to the board flattened ribs and tubercles of *T. Lamarcki*. From McCoy's *Prodromus of the Palaeontology of Victoria, Decade 2* (1875: pl. XIX).

important role in critically examining fossil evidence and relating it to the structure and lithology of a geological formation or region.

There was another factor in McCoy's readiness to fit Australian geology into a larger framework. He was attempting to defend a 'progressionist' but non-evolutionary view of the world. McCoy's geological view of the earth, like his mentor Adam Sedgwick's, was more compatible with classical Cuverian catastrophism than with Lyellian uniformitarianism. McCoy was staunchly anti-Darwinian and rigidly believed in successive progressive "creations"; for example, in the 1862 paper when he speaks of the change from the Mesozoic to the Tertiary, he states:

> "... we find that here, as in Europe, the greater part of the country sank under the sea during the Tertiary period, and every trace of the previous creations of plants and animals was destroyed and replaced by a totally different new set, both of plants and animals, more nearly related to those now occupying the land and sea of the country" (McCoy 1862: 144).

McCoy viewed these postulated successive creations in global terms.

One of the main motivations for publishing his findings on the Australian stratigraphy, as revealed by McCoy in the introduction to the 1862 paper, was to counter the argument (advanced by alleged "transmutationists" and "materialists" such as T.H. Huxley and others) that evolution occurred at highly variable rates in different regions of the globe and that Australia was, in essence, an evolutionary backwater. This was another consequence of the view that had gained credence since the time of Lamarck with the discovery of the bivalve *Trigonia* (Fig. 4) and the brachiopod *Magellania* in Australian waters and of various marsupials and plants which had become extinct in Europe. By demonstrating the universality of the geological column, and that the Southern Hemisphere, despite some provincialism, correlated geologically and biologically with the rest of the world, McCoy was attempting to demolish that argument, which, in fact, he effectively did. Unfortunately for McCoy the tide of scientific opinion was by now clearly running against progressionist ideas and his induction did little to change that. Indeed, by confirming the universality of the geological column he only helped prepare the way for a strict Lyellian uniformitarianism and thus the acceptance of gradual transmutation or evolution of organic species.

McCoy identified and described several new species of *Trigonia*. *Trigonia* was previously known only from Mesozoic formations — and in the living state in Australian waters — but was unknown in the Tertiary. McCoy was pleased to declare that he had filled that particular gap in the fossil record. In his *Prodromus of the Palaeontology of Victoria, Decade 2* (1875: 21) he wrote,

> "Being enabled to announce the discovery of three distinct species of *Trigonia* from the Pliocene and Miocene Tertiaries near Melbourne clears away this supposed exception to a general Palaeontological law, and cannot fail to be welcome, not only to geologists generally, but to the biologists engaged with the large question of the succession of life on our globe."

CONCLUSION

It is clear that Frederick McCoy made a seminal contribution towards deciphering Australian stratigraphy based on his northern hemisphere experience, and especially the key role he played in the Cambrian/Silurian debate between Adam Sedgwick and Roderick Murchison. He was the first to unambiguously and definitively demonstrate that the Australian geology and stratigraphy correlated fundamentally with that of the northern hemisphere contrary to the standard European view of the time. Debate has continued until the present day on just how complete the correlations actually are. It appears that McCoy's achievements were largely underrated by the British establishment in his day, and his critical contribution has gone almost entirely unnoticed and unacknowledged by modern historians. McCoy certainly received criticism on aspects of his work by some of his contemporaries and became embroiled in a number of controversies both locally in Australia and overseas in England and Ireland. Some of this condemnation has undoubtedly contributed towards a lack of appreciation of his more positive contributions.

Perhaps another reason McCoy's achievement is not more appreciated today is because the global geological column is now taken for granted. The realization that the Southern Hemisphere was, in general terms, geologically compatible with Europe and North America was an important confirmation of the universality of geological phenomena. McCoy's anti-evolutionary stance, which he shared with many of his contemporaries including Sedgwick and Murchison, is a further reason that his scientific achievements have not been widely

appreciated. As Rupke (1983) notes many of these pre-Darwinian and anti-Darwinian scientific contributors have been either harshly dealt with by historians, or dismissed and ignored.

Because of his extensive commitments as Director of the National Museum, Professor of Natural Science at the University of Melbourne, and numerous other duties such as descriptive zoological work, McCoy never approached the prodigious output that he achieved in Great Britain in his Australian palaeontological work. Funding difficulties, bureaucratic arguments and political complications also contributed to delays in publication. Work on his *Prodromus of the Palaeontology of Victoria*, published serially between 1874 and 1882, was actually started in 1858 — the series remained unfinished with the seventh issue or 'decade'. His *Prodromus of the Zoology of Victoria* was published in twenty decades between 1878 and 1890.

The breadth of McCoy's contributions to palaeontology and modern zoology, his scientific, philosophical and theological activities aimed at the public, and his administration of public institutions and societies, have made McCoy a difficult individual to grapple with. This difficulty should not blind us to the fact that in his day he was an eminent authority and made lasting contributions not only locally but to world science generally. He was one of the pioneering figures of international palaeontology and biostratigraphy and until the arrival on the local scene of Ralph Tate and Robert Etheridge, Jnr. (Vallance 1978: 247) he was Australia's leading palaeontologist and arguably in his mature years "the acknowledged chief of the scientific world of Australasia" (Anon. 1899: 283).

REFERENCES

ANON., 1899. Obituary. Professor Sir Frederick McCoy, K.C.M.G., M.A., D.Sc. (CANTAB), F.R.S., F.G.S. *Geological Magazine, New Series, Decade 4*, 6: 283–287.

ARCHBOLD, N. W., 2001. Frederick McCoy and the Phylum Brachiopoda. *The Victorian Naturalist* 118(5): 178–185.

BASSETT, D. A., 1991. Roderick Murchison's The Silurian System: A Sesquicentennial Tribute. In *The Murchison Symposium: proceedings of an international conference on The Silurian System*, M. G. Bassett, P. D. Lane & D. Edwards eds, The Palaeontological Association, London. *Special Papers in Palaeontology* 44: 7–90.

BERRY, W. B. N., 1968. *Growth of a Prehistoric Time Scale Based on Organic Evolution*. W. H. Freeman, San Francisco and London.

BRANAGAN, D. F., 1998. Geological Periodization. In *Sciences of the Earth. An Encyclopedia of Events, People, and Phenomena*, G. A. Good, ed., Garland Publishing, Inc., New York and London, Vol. 1: 306–314.

CONYBEARE, W. D. & PHILLIPS, W., 1822. *Outlines of the Geology of England and Wales, with an Introductory Compendium of the General Principles of that Science, and Comparative Views of the Structure of Foreign Countries*. William Phillips, London.

CRAIG, G. Y., 1971. Letters Concerning the Cambrian-Silurian Controversy of 1852. *Journal of the Geological Society of London* 127: 483–500.

DARRAGH, T. A., 1992. Frederick McCoy. *The Fossil Collector Bulletin* 36: 15–22.

DARRAGH, T. A., 2001. Frederick McCoy: the Irish Years. *The Victorian Naturalist* 118(5): 160–164.

FENDLEY, G. C., 1969. Sir Frederick McCoy (1817–1899). *Australian Dictionary of Biography* 1851–1890. 5: 134–136.

GOHAU, G., 1990. *A History of Geology*. Rutgers University Press, New Brunswick and London.

GRADSTEIN, F. M., OGG, J. G. et al., 2004. *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge.

GRIFFITH, R., 1841. *An address delivered at the ninth annual meeting of the Geological Society of Dublin, on the 12th of February 1840*. Hodges & Smith, Dublin.

HECKER, R. TH., 1987. Na Siluriiskom Plato. *Geologicheskikh Ocherki pa Istorii Znanii Vyp.* 24: 1–153.

HERRIES DAVIES, G. L., 1983. *Sheets of many colours. The mapping of Ireland's rocks 1750–1890*. Royal Dublin Society, Dublin.

HERRIES DAVIES, G. L., 1995. *North from the Hook. 150 years of the Geological Survey of Ireland*. Geological Survey of Ireland, Dublin.

HUDSON, J., 1843. *A complete guide to the Lakes ... with Mr Wordsworth's description of the scenery of the country, etc. and three letters on the geology of the Lake District by Professor Sedgwick*. Kendal.

INTERNATIONAL COMMISSION ON STRATIGRAPHY, 2004. *International Stratigraphic Chart*. International Commission on Stratigraphy, International Union of Geological Sciences.

IVANOVSKII, A. B., 1973. Istoriye Izucheniya Paleozoiskikh Korallov i Stomatoporoidei. Moskva, Izdatel'stvo 'Nauka'. *Akademiya Nauk SSSR, Sibirskoe Otdelenye, Trudy Institute Geologii i Geofiziki. Vypusk* 131: 1–288.

JUKES, J. B., 1846 (published 1843). A few remarks on the nomenclature and classification of rock formations in new countries. *The Tasmanian Journal of Natural Science* 2(6): 1–12.

JUKES, J. B., 1850. *A sketch of the physical structure of Australia, so far as it is at present known*. T. & W. Boone, London.

KONINCK, L. DE., 1842–1844. *Description des Animaux Fossiles qui se trouvent dans le Terrain Carbonifère de Belgique*. H. Dessain, Liege.

LAPWORTH, C., 1879. On the Tripartite Classification of the Lower Palaeozoic Rocks. *Geological Magazine, New Series, Decade 2* 6: 1–15.

LEICHHARDT, L., 1847. *Journal of an Overland Expedition in Australia, from Moreton Bay to Port Essington, a distance of upwards of 3000 miles, during the years 1844–1845*. T. and W. Boone, London.

McCOY, F., 1838. Remarks on Mr. Eyton's Arrangement of the Gulls. *Magazine of Natural History, New Series* 2: 487–490.

McCOY, F., 1839. On a new genus of Entomostraca from the Mountain Limestone. *Journal of the Geological Society of Dublin* 2: 91–94.

McCOY, F., 1844. *A Synopsis of the Characters of the Carboniferous Limestone Fossils of Ireland*. Dublin University Press, Dublin.

McCOY, F., 1846. *A Synopsis of the Silurian Fossils of Ireland*. Dublin University Press, Dublin.

McCOY, F., 1847. On the fossil botany and zoology of the rocks associated with the coal of Australia. *Annals and Magazine of Natural History* 20: 145–157, 226–236, 298–312.

McCOY, F., 1851. *Description of the British Palaeozoic fossils in the Geological Museum of the University of Cambridge. Fasciculus 1*. University of Cambridge Press, Cambridge.

McCOY, F., 1852. *Description of the British Palaeozoic fossils in the Geological Museum of the University of Cambridge. Fasciculus 2*. University of Cambridge Press, Cambridge.

McCOY, F., 1854. *Contributions to British Palaeontology, or first descriptions of three hundred and sixty species and several genera of fossil Radiata, Articulata, Mollusca, and Pisces from the Tertiary, Cretaceous, Oolitic, and Palaeozoic strata of Great Britain*. MacMillan and Co., Cambridge.

McCOY, F., 1855. *Description of the British Palaeozoic fossils in the Geological Museum of the University of Cambridge. Fasciculus 3*. University of Cambridge Press, Cambridge, University of Cambridge Press.

McCOY, F., 1861. On the Ancient and Recent Natural History of Victoria. *Catalogue of the Victorian Exhibition, 1861: With Prefatory Essays, indicating the Progress, Resources, and Physical Characteristics of the Colony*. John Ferres, Government Printer, Melbourne, 159–174.

McCOY, F., 1862. Note on the Ancient and Recent Natural History of Victoria. *Annals and Magazine of Natural History*, Series 3, 9: 137–150.

McCOY, F., 1865. Note on the Cretaceous deposits of Australia. *Annals and Magazine of Natural History*, Series 3, 16: 333–334.

McCOY, F., 1867a. On the recent zoology and palaeontology of Victoria. *Intercolonial Exhibition of Australasia, Melbourne, 1866–1867. Official Record, containing introduction, catalogues, reports and awards of the Jurors, and essays and statistics on the social and economic resources of the Australian Colonies*. Blundell & Co., Melbourne, 309–330 (1–24).

McCOY, F., 1867b. On the recent zoology and palaeontology of Victoria. *Annals and Magazine of Natural History*, Series 3, 20: 175–202.

McCOY, F., 1867c. On the Palaeontology of Victoria, South (sic) Australia. *American Journal of Science and Arts* 44: 279–282.

McCOY, F., 1874–1882. *Prodromus of the Palaeontology of Victoria; or, figures and descriptions of Victorian Organic Remains*. John Ferres, Government Printer, Melbourne.

McCOY, F., 1878–1890. *Prodromus of the Zoology of Victoria*, George Robertson, Melbourne and Trübner & Co., London.

McCOY, F., 1891. Minutes of evidence. Royal Commission on Coal. Final Report of the Royal Commission appointed to inquire as to the

best means of Developing and Promoting the Coal Industry in Victoria. *Victoria. Votes and Proceedings of the Legislative Assembly for the session 1891*, 6: 43–52.

MURCHISON, R. I., 1839. *The Silurian System, Founded on Geological Researches in the Counties of Salop, Hereford, Radnor, Montgomery, Caermarthen, Brecon, Pembroke, Monmouth, Gloucestor, Worcestor, and Stafford; With Descriptions of the Coal-fields and Overlying Formations.* John Murray, London.

MURCHISON, R. I., 1852. On the Meaning of the Term "Silurian System" as Adopted by Geologists in Various Countries During the Last Ten Years. *Quarterly Journal of the Geological Society of London* 8: 173–184.

MURCHISON, R. I., VERNEUIL, E. DE, et al., 1845. *The Geology of Russia in Europe and the Ural Mountains. Vol. 1.* John Murray, London.

PESCOTT, R. T. M., 1954. *Collections of a Century. The History of the First Hundred Years of the National Museum of Victoria.* National Museum of Victoria, Melbourne.

PHILLIPS, J., 1836. *Illustrations of the Geology of Yorkshire; or a description of the strata and organic remains: accompanied by a geological map, sections, and diagrams, and figures of the fossils. Part II. The Mountain Limestone District.* John Murray, London.

PHILLIPS, J., 1841. *Figures and descriptions of the Palaeozoic fossils of Cornwell, Devon and West Somerset; observed in the course of the Ordinance Geological Survey of that district.* Longman, Brown, Green & Longmans, London.

PHILLIPS, J., 1848. The Malvern Hills Compared with the Palaeozoic Districts of Abberley, &c. *Memoirs of the Geological Survey of Great Britain* 2: 1–386.

PORTER, R., 1977. *The making of geology. Earth science in Britain 1660–1815.* Cambridge University Press, Cambridge.

RASMUSSEN, C., 2001. *A museum for the people. A history of Museum Victoria and its predecessors, 1854–2000.* Scribe Publications, Melbourne.

RUDWICK, M. J. S., 1975. Adam Sedgwick. *Dictionary of Scientific Biography.* C. H. Gillispie (editor-in-chief). Charles Scribner's Sons, New York, 12: 275–279.

RUDWICK, M. J. S., 1985. *The Great Devonian Controversy. The Shaping of Scientific Knowledge Among Gentlemanly Specialists.* University of Chicago Press, Chicago and London.

RUPKE, N. A., 1983. *The Great Chain of History. William Buckland and the English School of Geology* (1814–1849). Clarendon Press, Oxford.

SECORD, J. A., 1986. *Controversy in Victorian geology. The Cambrian-Silurian dispute.* Princeton University Press, Princeton, New Jersey.

SEDGWICK, A., 1831a. Address. On announcing the first award of the Wollaston Prize. *Proceedings of the Geological Society of London* 1: 270–279.

SEDGWICK, A., 1831b. Address to the Geological Society, Delivered on the Evening of the 18th February 1831. *Proceedings of the Geological Society of London* 1: 281–316.

SEDGWICK, A., 1852. Sedgwick to Lord Lieutenant of Ireland, 13 December 1852, McCoy papers, Mitchell Library, State Library of New South Wales, CY reel 499: 294–7.

SEDGWICK, A. & MCCOY, F., 1855. A Synopsis of the Classification of the British Palaeozoic Rocks. *A Synopsis of the Classification of the British Palaeozoic Rocks, by the Rev. Adam Sedgwick, M.A. F.R.S., with a Systematic Description of the British Palaeozoic Fossils in the Geological Museum of the University of Cambridge, by Frederick McCoy, F.G.S. Hon. F.C.P.S.*, John W. Parker and Son, London; Deighton, Bell & Co. and Macmillan & Co., Cambridge.

SEDGWICK, A. & MURCHISON, R. I., 1836. On the Silurian and Cambrian Systems, Exhibiting the Order in Which the Older Sedimentary Strata Succeed Each Other in England and Wales. *British Association for the Advancement of Science, 1835 Report, Part 2*: 59–61.

SPEAKMAN, C., 1982. *Adam Sedgwick, Geologist and Dalesman, 1785–1873. A Biography in Twelve Themes.* Heathfield, East Sussex, Published jointly by The Broad Oak Press Limited, The Geological Society of London and Trinity College, Cambridge.

STAFFORD, R. A., 1989. *Scientist of Empire. Sir Roderick Murchison, Scientific Exploration and Victorian Imperialism.* Cambridge University Press, Cambridge.

STRZELECKI, P. E., 1845. *Physical description of New South Wales and Van Diemen's Land*. Longman, Brown, Green, London.

TATE, R., 1894. Inaugural address. *Report of the Fifth meeting of the Australian Association for the Advancement of Science held at Adelaide, South Australia, September 1893*. R. Tate. E. H. Rennie & W. H. Bragg, eds, Australian Association for the Advancement of Science, Adelaide, 1–69.

THACKRAY, J. C., 1978. R. I. Murchison's *Silurian System* (1839). *Journal of the Society for the Bibliography of Natural History* 9(1): 61–73.

VALLANCE, T. G., 1975. Origins of Australian geology. *Proceedings of the Linnean Society of New South Wales* 100(1): 13–43.

VALLANCE, T. G., 1978. Pioneers and leaders — a record of Australian palaeontology. *Alcheringa* 2: 243–250.

WILKINSON, I., 1996. The Battle for the Museum. Frederick McCoy and the Establishment of the National Museum of Victoria at the University of Melbourne. *Historical Records of Australian Science* 11: 1–11.

WOODWARD, H. B., 1907. *The history of the Geological Society of London*. Geological Society of London, London.

WYSE JACKSON, P. N. & MONAGHAN, N. T., 1994. Frederick McCoy. An eminent Victorian palaeontologist and his synopsis of Irish Palaeontology of 1844 and 1846. *Geology Today* 10: 231–234.

ZITTEL, K. A. VON, 1901 (Reprinted 1962). *History of Geology & Palaeontology to the End of the Nineteenth Century*. Walter Scott, London.

SEQUENCE AND EVENT STRATIGRAPHY OF SILURIAN STRATA OF THE CINCINNATI ARCH REGION: CORRELATIONS WITH NEW YORK-ONTARIO SUCCESSIONS

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The Lower Silurian (Llandovery-Wenlock) of the eastern Cincinnati Arch in south central Ohio and northern Kentucky, USA, has been restudied from the standpoint of sequence and event stratigraphy. Despite a multiplicity of local stratigraphic terms a relatively simple pattern emerges. The succession, which comprises a major portion of the Tutelo Supersequence, is bounded at the base by the Cherokee Unconformity. It is further divisible into a series of six third order composite sequences and component fourth order subsequences that are correlative with Silurian sequences S-I, S-II and S-IV to S-VII, previously recognized in the Appalachian Basin. As in western New York-Ontario, sequence S-III has been removed by erosion at a major regionally angular late Llandovery unconformity. Correlation is corroborated by biostratigraphy and distinct event beds, including a very widespread deformed horizon (probable seismite), faunal epiboles, reef horizons, and probable K-bentonites. Similar patterns in the Silurian of the Niagara Escarpment in southern Ontario and western New York indicate probable allocyclic (eustatic) control over sequence development. However, the relatively simple sequence patterns are locally modified by epeirogenic uplift and subsidence. In particular, major truncation below sequence S-IV and thinning of strata in higher sequences to the west in Ontario and in western Ohio indicate that the Findlay-Algonquin Arch system was a positive area (forebulge?) by later Llandovery time. Moreover, a second area of regional uplift developed to the southwest in the vicinity of north central Kentucky during Wenlock time, as indicated by thinning and erosional truncation of parts of sequences S-V and S-VI. Changing loci of local uplift, as well as widespread K-bentonites and a major seismite are indicative of renewed tectonism of the Salinic Orogeny during this time.

Keywords: Silurian, Cincinnati Arch, sequence stratigraphy, eustasy, tectonics

IN recent years outcrop-based stratigraphic studies in cratonic areas have undergone a paradigmatic shift from a primarily descriptive approach to a focus on understanding the architecture of sedimentary accumulations within a sequence stratigraphic context (Wilgus et al. 1988; Kidwell 1991; Holland 1993, 1998; Dennison & Ettensohn 1994; Brett 1995, 1998; Emery & Myers 1996; Witzke et al. 1996; Catuneanu 2002; Coe & Church 2004). This avenue of research has developed indirectly from seismic profiling of continental margin sediments and from the recognition of large, unconformity-bounded depositional wedges ("sequences") in these profiles. Originally, sequences were defined very broadly as large intervals of strata bounded by very major unconformities ("first-" or "second-order" cycles recording tens of millions of years; see Vail et al. 1977, 1991), such as the six classic "super sequences" of Sloss (1963). Seismic stratigraphers were able to refine correlations and demonstrate that these large-scale unconformity-bounded packages are subdivisible into smaller intervals representing approximately 0.5 to 3 million years, typically termed "third-order" sequences. Sequence stratigraphers also recognized distinctive phases of sequences ("systems tracts") as the product of sea-level oscillations translated in a biased way into the sedimentary record (Vail et al. 1977, 1991; Haq et al. 1987; Van Wagoner et al. 1988; Emery & Myers 1996). Subsequently, seismic stratigraphers working in the field recognized that third-order packages could frequently be subdivided into smaller scale, "fourth-", "fifth-", and even "sixth-" and higher order cycles.

The purpose of this contribution is to examine and discuss Silurian strata of the eastern Cincinnati Arch region in eastern North America (Figs. 1, 2) in the context of sequence stratigraphy. Research on the sequence stratigraphy of Silurian rocks in the

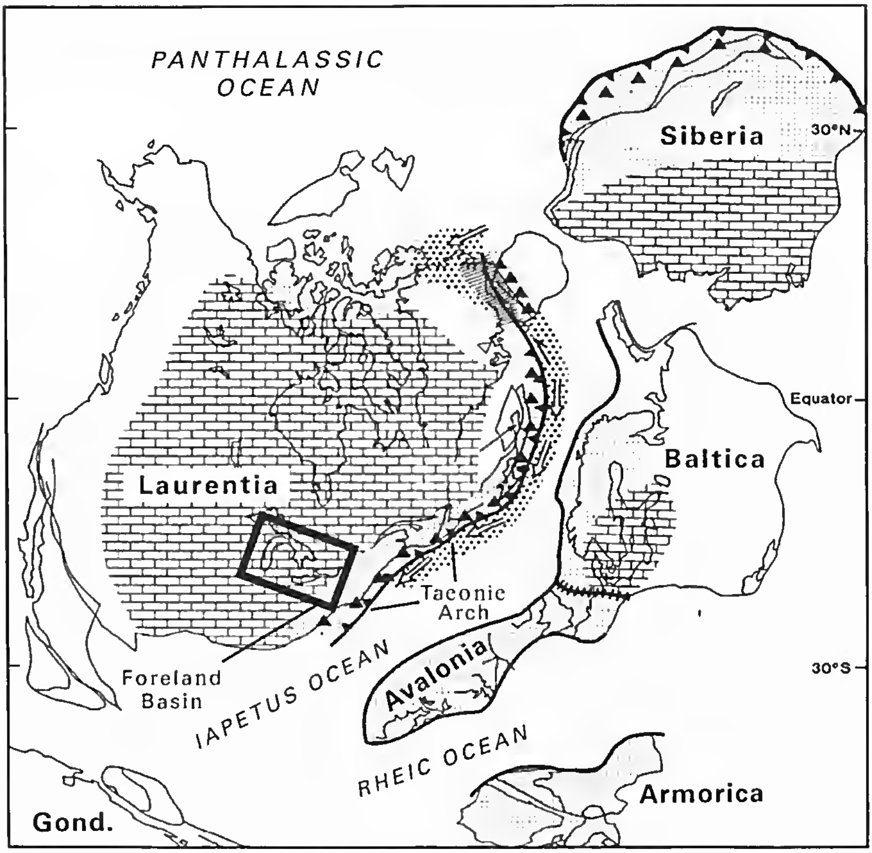

Fig 1. Paleogeographic reconstruction of Laurentia (ancestral North America) and adjacent paleocontinents during Early Silurian time. Note position of study area, shown with box and of the Taconic Arch and peripheral foreland basion. Gond.: Gondwana. Modified from Scotese (1990).

northern Appalachian Basin (Brett et al. 1990, 1994, 1998) has resulted in recognition of about eight widespread, unconformity-bounded packages that may be assigned "third-order" status, as well as a large number of smaller ("fourth-order") sequences. Recently, sequence analysis of correlative units in Ohio and Kentucky, USA, has led to recognition of about six, probably correlative "third-order" sequences in the Cincinnati Arch region (Fig. 2). Interregional correlation of these sequences is facilitated by the conodont biostratigraphic studies of Kleffner (1989) as well as the detailed subsurface study of Lukasik (1988).

We believe that the application of sequence analysis to this classic stratigraphic succession is providing critical new insights into the depositional dynamics and history of this region. In turn, these well-exposed strata may potentially help to refine models and approaches to stratigraphy that will aid in interpretation of other areas.

GEOLOGIC SETTING

Sediments of Early Silurian (Llandovery-Wenlock) age in southern Ohio and northern Kentucky accumulated in a shallow-marine subtropical setting about 20–25° south of the palaeoequator (Scotese 1990; Ettensohn 1992a,b; Figs. 1, 2). This setting was well situated to be affected by subtropical hurricanes and there is abundant evidence for storm deposition (tempestites) in the Silurian.

During the Late Ordovician, eastern Laurentia underwent collisions with island arc to microcontinental terranes, first (during the early Turinian or mid Caradoc Age) in the southern Appalachian region where collision produced the Blountian highlands and later (during the late Shermanian; late Caradoc) in the area of the New York Promontory where the Hamburg Klippe (SE Pennsylvania) and Taconic allochthons were emplaced as accretionary wedges onto the

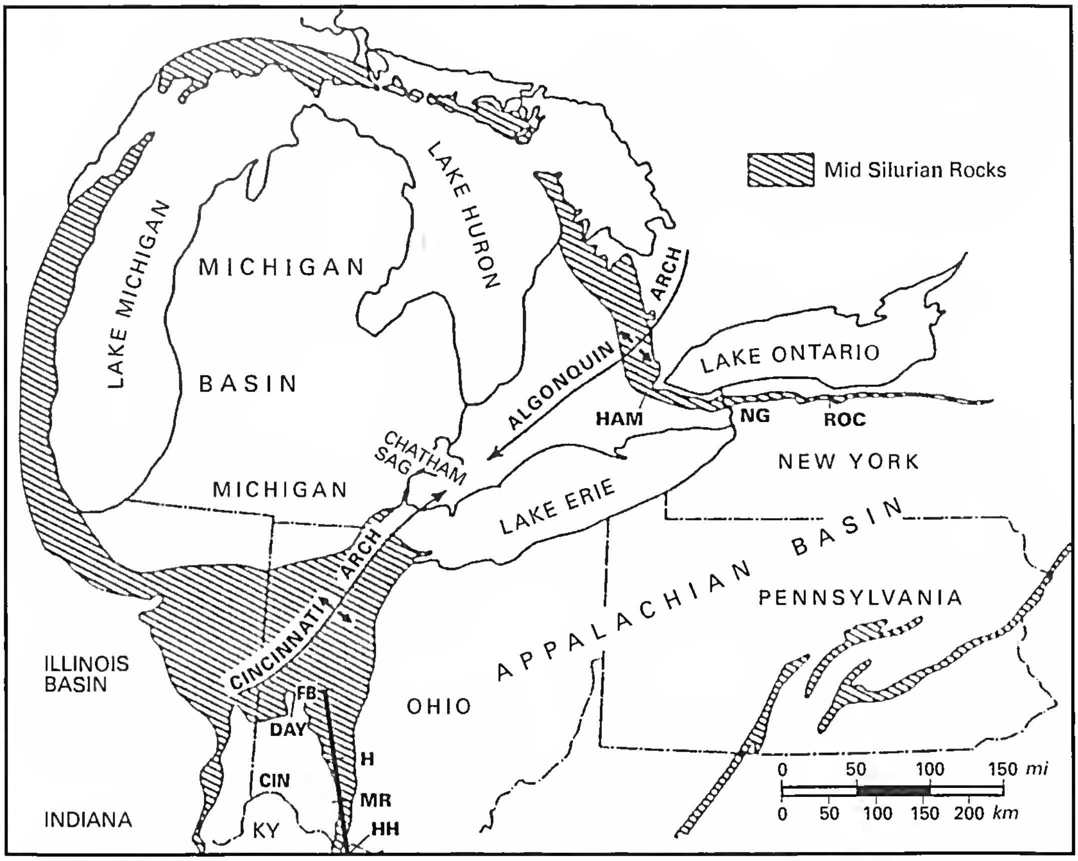

Fig 2. Map showing geomorphic features of eastern North America and outcrop belt of the Silurian; bar shows position of cross sections in Figures 6 (in part) and 14; abbreviations:DAY: Dayton, Ohio; CIN.: Cincinnati, Ohio; FB: Fairborn Quarry near Dayton, Ohio; HAM: Hamilton, ONT; H: roadcut on Rte. 62 at Hillsboro, Ohio; HH: Cut on AA Highway at Herron Hill, Kentucky; MR: cut on US Rte. 32 at Measley Ridge, near Peebles, Ohio; NG: Niagara Gorge, NY, ONT; ROCH: Rochester, NY. Base map modified from Telford (1978).

Laurentian margin forming the Taconian highlands (Ettensohn 1992c; Ettensohn & Pashin 1992; Fig. 1). Most of the siliciclastic muds and silts of the Upper Ordovician (Cincinnatian) and Lower Silurian were probably derived from these upland areas to the east and southeast. A relatively small gap existed between the two upland regions that might have served to funnel storms into the present-day Tristate region (Ohio-Kentucky-Indiana; Ettensohn 1992b, 2004).

The Taconic foreland basin (Fig. 1), a relatively narrow trough produced by thrust loading, extended southward from Quebec to Alabama (Beaumont et al. 1988; Ettensohn 1991; Ettensohn & Brett 2002). This area of active subsidence accumulated a thick wedge (up to 3900 m) of siliciclastic sands, silts and muds during the Late Ordovician- Early Silurian (Ettensohn 2004).

During the latest Ordovician to early Silurian, a major sea-level lowstand, probably related to continental glaciation in Gondwana (Brenchley et al. 1994; Brenchley 2004), caused the widespread withdrawal of seas from the Cincinnati area and created a major erosion surface, the Cherokee Unconformity (Figs. 3, 4). Evidence for local Llandovery glacial and interglacial events in South America (Grahn & Caputo 1992) suggests glacioeustatic control at least on Early Silurian cycles. Transgression in the Early Silurian (Rhuddanian) enabled deposition of marine siliciclastics and carbonates over the unconformity. This transgression spread a clastic wedge over much of the Appalachian Basin but clastic influx appears to have had rather little influence in the study area in which Brassfield carbonates were deposited contemporaneously (Gordon & Ettensohn 1984).

The Early Silurian interval is typically considered to have been tectonically quiescent. However, recent study (Ettensohn & Brett 2002; Ettensohn 2004; Fig. 3) indicates that a late tectophase of the Taconic Orogeny may have taken place at this time. Furthermore, a cluster of Early Silurian K-bentonites in the southern Appalachians indicates ongoing volcanism during this time (Huff et al. 1997). There is also some evidence for renewed tectonism, which produced renewed subsidence and a pulse of siliciclastics into the Appalachian basin during medial Silurian (latest Llandovery) time (Ettensohn 2004). In addition, recently discovered K-bentonites provide evidence for increased volcanism during late Llandovery-mid Wenlock time (Huff et al. 1997; Ray & Brett 2001; Brett & Ray 2001). Locally, evidence for renewed tectonism is provided not only by thick shales and siltstones of the Crab Orchard-Estill formations, but also by development of regional angular unconformities (Lukasik 1988; Goodman & Brett 1994; Ettensohn & Brett 1998; Figs. 3, 4). Regional truncation of Lower Silurian units in central Ohio and northward into the Hamilton, Ontario, area suggests that the Findlay-Algonquin Arch, the northeastern branch of the Cincinnati Arch, was uplifted during late Llandovery time (Ettensohn & Pashin 1992). The affected area cuts obliquely across the position of the former Sebree Trough. This could be viewed as evidence of reactivation of older deep-seated structures related to basement faults, but it has also been interpreted as development of a forebulge related to thrust loading and subsidence in the adjacent Appalachian foreland basin. In a sense, this could be viewed as the origin of the Cincinnati Arch (Ettensohn & Pashin 1992), although, in fact, the area of uplift was offset from the center of the present structural arch. The new stratigraphic correlations presented here will ultimately be used to refine understanding of migrating arches (forebulges) and depocenters through the Silurian.

GENERAL STRATIGRAPHY OF SILURIAN STRATA OF THE EASTERN CINCINNATI ARCH

Study Area and Methods

Recently, a series of detailed stratigraphic sections have been measured and correlated in southern Ohio into northern Kentucky along an approximately northwest-southeast line totaling about 170 km from the northern to the western flank of the present Cincinnati Arch, a broad, gentle antiformal feature that occupies portions of Ohio, Indiana, and Kentucky (Figs. 2, 4; Ettensohn & Pashin 1992). Measured sections span from Ludlow Corners, northwest of Dayton, Ohio southeastward through Highland and Adams counties, and across the Ohio River to cuts along the AA Highway near Vanceburg, Kentucky. Although this cross section takes in areas of disparate stratigraphic nomenclature, correlation of units appears relatively straightforward, at least when regional truncation of beds at unconformities is taken into account. Previous correlations were complicated by misidentification of the Estill (Crab Orchard) Shale with the somewhat younger, and lithologically distinctive Rochester Shale of New York and Ontario (cf. Potter et al. 1991). Also, the Laurel Formation of Indiana was incorrectly correlated with a thin carbonate beneath the Massie Shale in the Dayton area rather than with the Euphemia-lower Lilly formations (see Figures 12, 14, herein). Finally, while previous workers recognized an important unconformity

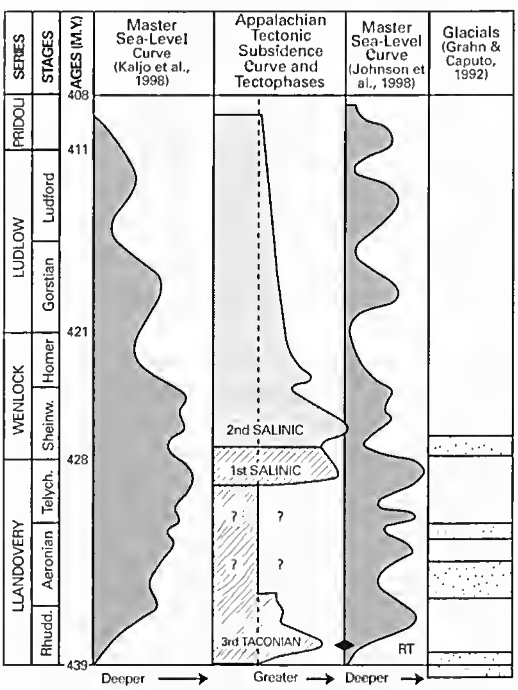

Fig 3. Silurian eustatic and tectonic events; note two slightly differing sea-level curves; tectophases include an early Llandovery pulse of the Taconic Orogeny and at least two tectophases of the Silurian Salinic Orogeny; also shown are documented ages of glacial deposits in South America. Modified from Ettensohn and Brett (1998).

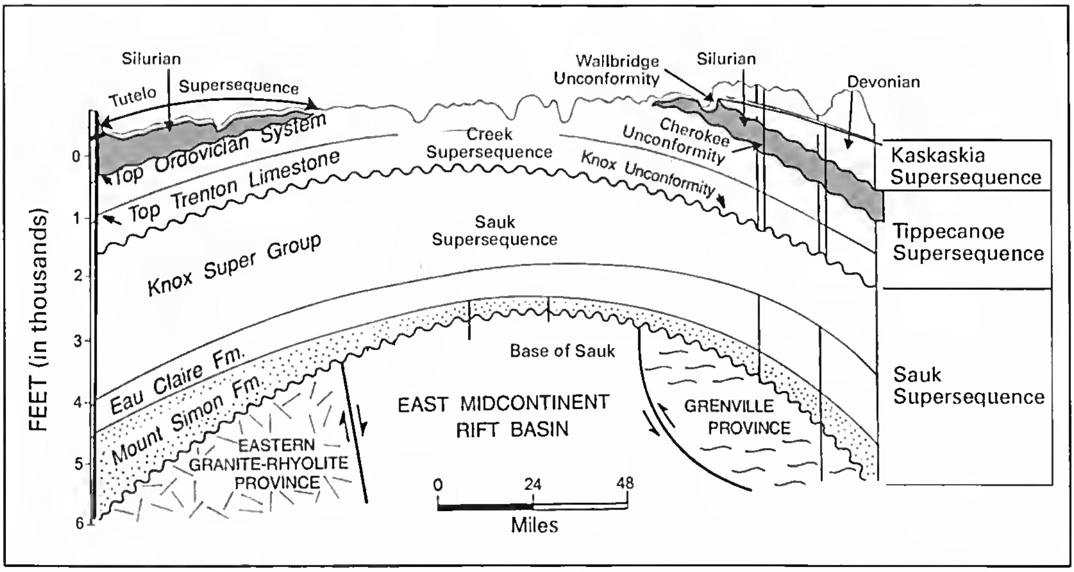

Fig 4. Schematic cross section of the Cincinnati arch region of southern Ohio/northern Kentucky, showing unconformities (supersequence boundaries) and Sloss sequences in the Ordovician. Note truncation of Silurian in center of arch. Adapted from Potter (1996).

beneath the Dayton Formation (Foerste 1906, 1935; Lukasik 1988), they failed to identify key sequence bounding truncation surfaces within the Bisher Formation and at the base of the Lilly Dolostone. Once these truncation surfaces were recognized the regional stratigraphic pattern was clarified and new patterns of paleogeography became evident.

Initially, we suspected that the Dayton-Vanceburg cross section would provide details of expansion of strata from the Algonquin Arch into the Appalachian foreland. However, it became clear that, while some Lower Silurian units (e.g., Estill Shale) showed a general southeastward expansion in thickness, upper units displayed a more complex pattern. In particular, the Massie (=Rochester) Shale thins both to the northwest and to the southeast of a maximum in Highland Co., Ohio. These observations suggest that the Findlay-Algonquin Arch was active during the middle to late Llandovery. A secondary arch developed later during the medial Silurian, in the vicinity of the later Waverly Arch in northern Kentucky.

Supersequences

At the largest scale, the rocks of the Cincinnati Arch-Appalachian Basin region are subdivisible into great unconformity-bounded packages of the scale recognized long ago by Sloss (1963). These large-scale "supersequences" are bounded by major unconformities that are traceable widely over the North American craton and perhaps globally (Dennison & Ettensohn 1994; Figs. 3, 4).

At their top, the Upper Ordovician rocks are bounded by a second great unconformity, the Cherokee Unconformity (Dennison & Head 1975). This unconformity is of global extent but of shorter duration (3–4 million years) than the Knox Unconformity, at the base of the Middle Ordovician Creek Supersequencee, having removed only the uppermost Ordovician Gamachian Stage over most of North America (Fig. 4). The Cherokee Unconformity is typically attributed to a major lowstand or drop in global sea level, probably of glacio-eustatic origin and related to coeval continental glaciation in North Africa (Brenchley et al. 1994; Brenchley 2004). This unconformity is typically nearly planar in outcrop but may display minor relief. In southern Ohio and northern Kentucky, the unconformity is in places very sharply delineated at the top of Upper Ordovician shales of the Drakes Formation, a greenish to red mottled mudstone with abundant thin siltstone layers that appears to represent the distal feather edge of the Queenston clastic wedge (Fig. 5). These variegated mudstones are sharply overlain by the Early Silurian (Rhuddanian) Brassfield Dolostone (Gordon & Ettensohn 1984). Although the Cherokee Unconformity is typically nearly flat and featureless, it

clearly truncates different units in various localities and is a regionally angular beveled surface.

The Silurian strata are typically assigned to the Tutelo Supersequence (formerly combined with Creek as the Tippecanoe Megasequence of Sloss 1963; Fig. 4). The top of the Silurian in eastern Kentucky and southern Ohio is defined by a second major "second-order" sequence boundary comprising actually a combination of two or more unconformities. The lower, or Wallbridge Unconformity, separates upper Lower to Middle Devonian (Emsian-Eifelian) deposits of the Kaskaskia Supersequence (Sloss 1963; Dennison & Head 1975) from Upper Silurian to Lower Devonian deposits. In most areas of the Midcontinent, a higher Taghanic unconformity that occurred during a late Middle Devonian sea-level drawdown oversteps the Wallbridge Unconformity, and Middle Devonian deposits are absent. Both unconformities appear to record a combination of tectonic and eustatic signatures in their formation (Ettensohn 2004).

SEQUENCE STRATIGRAPHY OF SILURIAN STRATA OF CINCINNATI ARCH REGION

Cratonic Third OrderSequence Stratigraphy: General Concepts

Decameter-scale unconformity-bounded depositional sequences are present within the Silurian strata of the Cincinnati Arch region (Fig. 6). These are comparable in duration (1 to 5 million years) to the "third-order" sequences recognized by seismic stratigraphers (see for example Vail et al. 1991). In particular, they are subdivisible into smaller-scale sequences, parasequences, and systems tracts. Before discussing these stratigraphic packages in detail, the basic concepts of sequence stratigraphy will be reviewed briefly (see Catuneanu 2002; Coe & Church 2003 and, for recent summaries).

Sequences are relatively conformable packages of strata bounded by unconformities formed during sea-level lowstands. It has been recognized for some time that larger scale sequences typically are over generalized and that most such sequences are in fact composite sequences (Myers & Milton 1996). Such composite sequences can be subdivided into smaller scale cyclic intervals. Some of these are unconformity-bounded units that exhibit a pattern of relative deepening followed by shallowing (sub-sequences of Brett et al. 1990), whereas others are distinctly asymmetrical units that mainly record shallowing (parasequences of Vail et al. 1991).

Based partly upon the stacking patterns of parasequences, or architecture, of portions of sedimentary sequences, stratigraphers have been able to recognize distinct groupings of facies within sequences, referred to as systems tracts. Briefly, these include lowstand (LST), transgressive (TST), highstand (HST), and falling stage (FSST, or regressive) systems tracts. The lowstand systems tract (LST) is

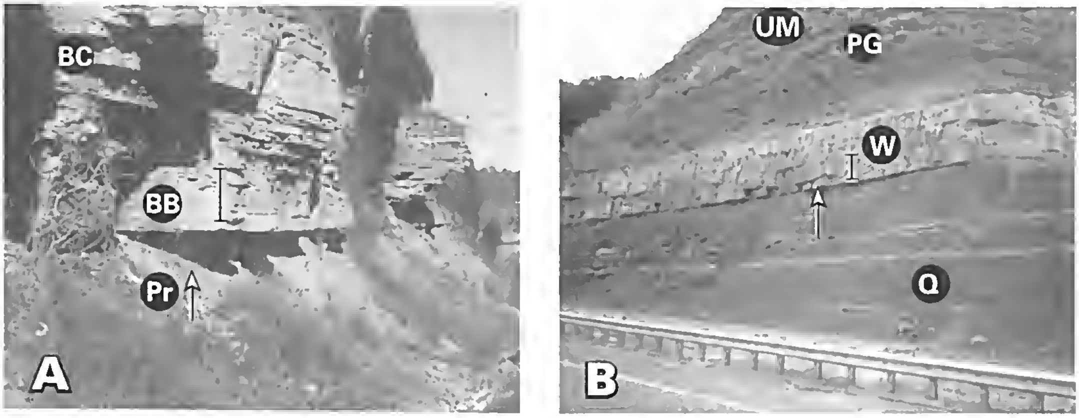

Fig 5. Cherokee Unconformity (shown with arrows) between Upper Ordovician (Richmondian; Ashgill Stage) shales and overlying Lower Silurian (Llandovery; Rhuddanian) beds. A) Preachersville Shale Mbr. (Pr) of the Drakes Formation, sharply overlain by Belfast Member of Brassfield Formation (BB), lower massive cherty unit (BC); cut along KY Rte. 10, just west of Cabin Creek, Tollesboro, Lewis Co., KY. B) Queenston Shale (redbeds; Q) sharply overlain by white Whirlpool Sandstone (W); sharp flooding surface separates sandstone from overlying dark grey Power Glen (Cabot Head) Shale (PG), in turn sharply overlain by upper Medina Group (UM) reddish sandstones; West Jackson Street, Lockport, Niagara Co., NY.

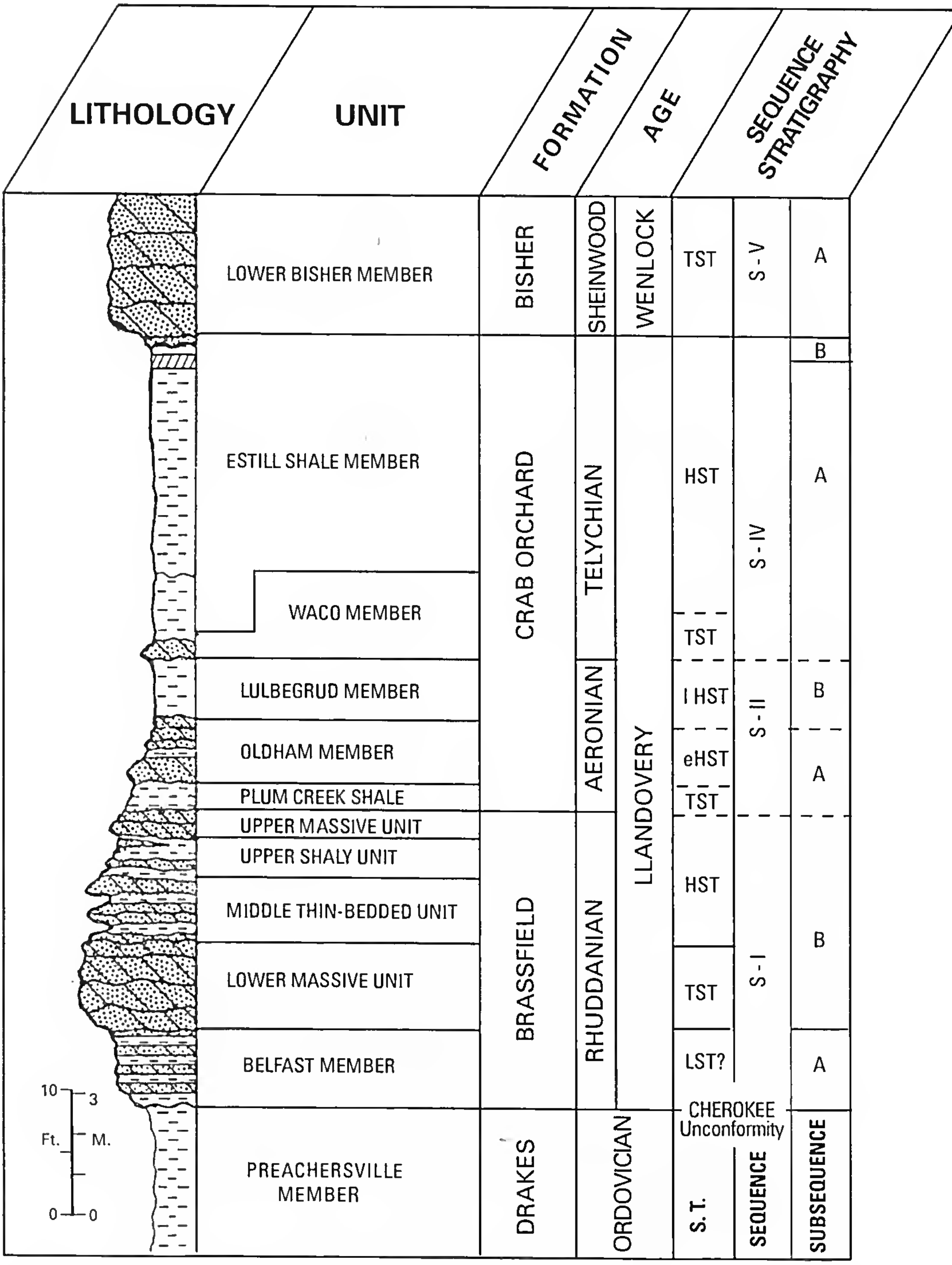

Fig 6. Generalized stratigraphic column and sequence stratigraphic interpretation for Lower Silurian (Llandovery) units in central Kentucky and south-central Ohio. Abbreviations: S.T.: systems tracts; LST: lowstand systems tract; TST: transgressive systems tract; eHST; early highstand systems tract; lHST late highstand systems tract. Note that each major (third-order) sequence is divisible into sub-sequences (sensu Brett et al., 1990), or fourth order sequences, labeled A and B. Stratigraphic profile adapted from Gordon & Ettensohn (1984).

defined as sediments that accumulate between true lowest actual fall of sea level and the beginnings of more rapid rates of sea level rise; these deposits include non-marine channel fillings that may occur locally immediately above a sequence boundary or erosion surface. In deeper water areas turbidite fans are another potential expression of lowstand accumulation during times when sediments are flushed from shallow water areas into deeper water regions. However, in most shallow shelf and ramp settings there are no LST deposits and the transgressive surface is superimposed upon the erosional sequence boundary (Myers & Milton 1996; Catuneanu 2002).

The transgressive systems tract (TST) may show a sharp transgressive erosion surface at its base, referred to as a ravinement surface. This transgressive surface reflects relatively rapid onlap of marine waters over a broad area. In many cases, including most of the sequences discussed herein, the sequence boundary and transgressive surfaces are combined into a single erosion surface, the ET surface (Myers & Milton 1996). The transgressive systems tract (TST) itself shows a deepening upward, retrogradational stacking pattern of smaller scale cycles or parasequences, and is bounded at its top by a surface of maximum flooding. This surface, which may be very distinct in some sequences, represents a time of minimal sedimentation in offshore marine settings associated with rapid sea-level rise, drowning of coastlines, and sequestering of siliciclastic sediments in nearshore estuarine and lagoonal depositional settings. Maximum flooding surfaces in the Silurian of eastern North America are typically marked by distinct but thin lag accumulations, phosphatic nodules, oolitic ironstones, or corroded shells and conodont enrichments (Brett et al. 1998). Immediately underlying and overlying the maximum flooding surface is a thin, time-rich section referred to as a condensed section that represents strongly sediment-starved conditions at times of maximum deepening.

The highstand systems (HST) tract typically commences with deeper water deposits, such as dark shales, that sharply overlie the maximum flooding surface. The highstand systems tract reflects sedimentation during the late portion of sea level rise; HSTs may show a progradational succession of smaller parasequences, i.e., an overall shallowing-upward pattern. In many instances, the HST can be differentiated from a falling stage (FSST) or regressive phase, in which progradational stacking of parasequences reflects an abrupt overall upward-shallowing (Catuneaunu 2003). Typically a sharp forced regression surface demarcates the base of the FSST, and, in some cases, a thin condensed lag bed may occur at this boundary (Brett 1995). The falling stage systems tract exhibits an overall shallowing and may be truncated at its top by the next major sequence boundary.

Description of Silurian Third Order Depositional Sequences

In the following sections the general sequence stratigraphy of the Lower Silurian in Ohio and Kentucky is described in ascending order and compared with reference sections in the north-central Appalachian Basin (Figs. 6, 7). The final section of this paper discusses the implications of revised stratigraphy for paleogeography, eustatic sea-level, and regional tectonics.

Sequence S-I. The first Silurian sequence (S-I) is the Medina or Tuscarora sandstone succession of the Appalachian Basin, which is recorded by the Lower Silurian (lower Llandovery) Brassfield Formation in Ohio and Kentucky (Figs. 5–7). It is bounded at its base by the Cherokee Unconformity (Fig. 5) and at its top by a more subtle and previously unrecognized sequence boundary marked by hematitic-phosphatic beds near the top of the Brassfield (Fig. 8). The equivalent sequence in western New York and Ontario consists of the Medina Group, comprising grey to reddish shales and sandstones (Brett et al. 1998; Fig. 7).

In the Cincinnati Arch region, the S-I basal unit is the Belfast Member of the Brassfield Formation (Fig. 8), an argillaceous dolostone and dolomitic shale that may resemble the underlying Drakes dolomitic shales. This interval apparently represents lowstand or initial transgressive conditions (Ettensohn 1992d). The basal bed of the Belfast Member is a massive, heavily bioturbated dolowackestone, 0.5 to 1 m thick; immediately above the sequence boundary the Belfast locally features a phosphatic, glauconitic lag. In central Kentucky this bed is a massive slightly glauconitic dolostone with spar filled burrow galleries near its top. The basal bed is sparsely fossiliferous, but contains scattered rugose corals and poorly preserved brachiopods. Locally it passes upward into a thin (0–0.5 m) interval of thin-bedded argillaceous dolostones and shales. The Belfast has been correlated with the Edgewood and Kankakee formations and, as with these units, is assigned an early Llandovery (Rhuddanian; sub-*Icriodina* Zone) age (Rexroad 1970; Berry & Boucot 1970). This

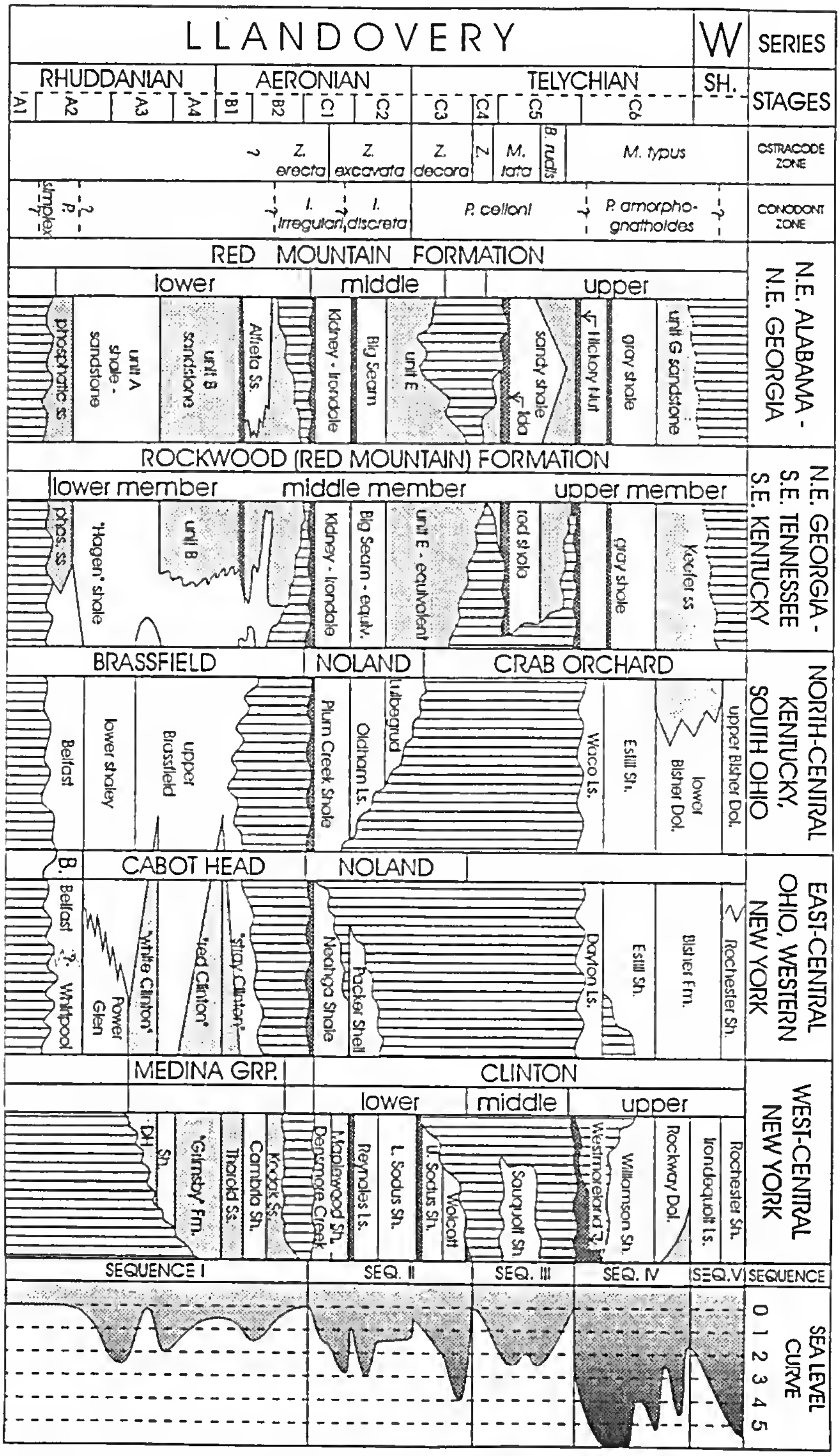

Fig 7. Correlation of Lower Silurian sequences in eastern USA; note particularly the comparisons of Kentucky, Ohio, and New York State. Curve on right side of diagram shows relative sea level curve for central New York State calibrated to benthic assemblages (BA-: shoreline, BA-2 above wave base; BA-3: average storm wavebase; BA-4 deep storm wavebase; see Brett et al. (1993) for discussion of depths of these assemblages. From Brett et al. (1998).

interval, together with the basal glauconitic bed, appears to form a transgressive-highstand couplet of a distinct minor (fourth-order) sequence, perhaps equivalent to the Whirlpool Sandstone in New York and Ontario (Fig. 5B). However, at the third-order scale this interval is interpreted to represent lowstand deposits of composite sequence S-I.

The next interval of the Brassfield Formation, (lower massive unit of Gordon & Ettensohn (1984) is a massive 1.5–3 m, orange buff-weathering crinoidal dolostone, typically with layers of light grey chert. The basal contact of the massive unit is sharp, and locally truncates some or all of the Belfast Member (Gordon & Ettensohn 1984; Fig. 8). This unit contains some fossils in common with the Manitoulin Formation of Ontario, its probable lateral equivalent. Both the Manitoulin and the bulk of the Brassfield Formation have been assigned to the Rhuddanian on the basis of conodonts of the *Icriodina irregularis* Zone (Rexroad 1970) and, in Ohio, brachiopods of the *Platymerella* Zone (Berry & Boucot 1970). Like the Manitoulin, the cherty Brassfield is interpreted as the upper portion of the TST of sequence S-I. The remainder of the Brassfield in southern Ohio and Kentucky consists of 8–10 m of thin-bedded, rippled dolostones that pass upward, into greenish grey shale and dolomitic siltstones, interpreted as tempestites (middle thin-bedded and upper shaly units of Gordon and Ettensohn 1984; Ettensohn 1992d; Fig.8). This interval probably constitutes the HST of sequence S-I and corresponds to the Cabot Head Formation of northern Ohio, Michigan and Ontario. Locally, near Dayton, the lower portion of this succession contains moderate sized bioherms or mud mounds with abundant pelmatozoan holdfasts, bryozoans, corals, and stromatoporoids

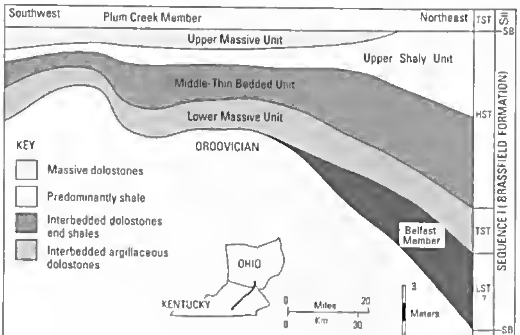

Fig 8. Regional cross-section of the Brassfield Formation in southern Ohio and northern Kentucky, showing distribution of sub-units. Sequence stratigraphic abbreviations as in Fig. 6. Adapted from Gordon and Ettensohn (1984).

(Lebold 2001; Schnieder & Ausich 2002). This occurrence indicates the buildup of bioherms during clean water conditions and rising sea level.

Sequence S-II. The second major Silurian sequence (S-II) is represented by a thin, poorly exposed succession assigned to the Noland or Crab Orchard Formations (or groups) in southern Ohio and northern Kentucky, respectively (Figs. 6, 7). It corresponds to the lower part of the Clinton Group, mixed shales, carbonates and ironstones, in the Appalachian Basin (Figs. 7, 9).

The base of this sequence is represented by a dolostone unit that is capped by a hematitic bed rich in large discoidal pelmatozoan columnals, the so-called "Bead Bed" (Foerste 1935) or upper massive unit of the Brassfield (Gordon & Ettensohn 1984; Ettensohn 1992d; Fig. 8); this unit locally contains an abundance of the brachiopod *Cryptothyrella subquadrata* (formerly *Whitfieldella subquadrata*) and was mapped widely, as the "*Whitfieldella*" bed in central Kentucky by Foerste (1906). Most authors have included the "Bead Bed" as an uppermost unit in the Brassfield, but Gordon & Ettensohn (1984) recognized that it represents part of a distinct sequence. The base of this bed is sharply set off from the underlying shales of the uppermost Brassfield succession and represents the sequence boundary. We interpret the Bead Bed as a transgressive systems tract; the abundance of hematite and phosphatic nodules at the top of the interval indicates prolonged sediment starvation associated with maximum rates of sea level rise. This bed has a counterpart in the early Llandovery Densmore Creek phosphatic bed and Webster bed phosphatic conglomerate in New York State (LoDuca & Brett 1994; Fig. 9).

The main Plum Creek Member of the Noland Formation in southern Ohio and central Kentucky consists of about 1–2 m of greenish grey, sparsely fossiliferous shale, dated as late Rhuddanian to early Aeronian age (Berry & Boucot 1970); we equate this unit with the Maplewood-Neahga shales of western New York (Figs. 7, 9) and to the lowest tongue of the Rose Hill Shale in Pennsylvania. As with those units, the Plum Creek is sparsely fossiliferous, but passes laterally into skeletal limestones and becomes indistinguishable from the Oldham Limestone in the area of Berea, Kentucky (Foerste 1906). This suggests that the Plum Creek may represent an "in-board" or lagoonal shale, as is the Maplewood, that passes westward into offshore shoal carbonates (see LoDuca & Brett 1994).

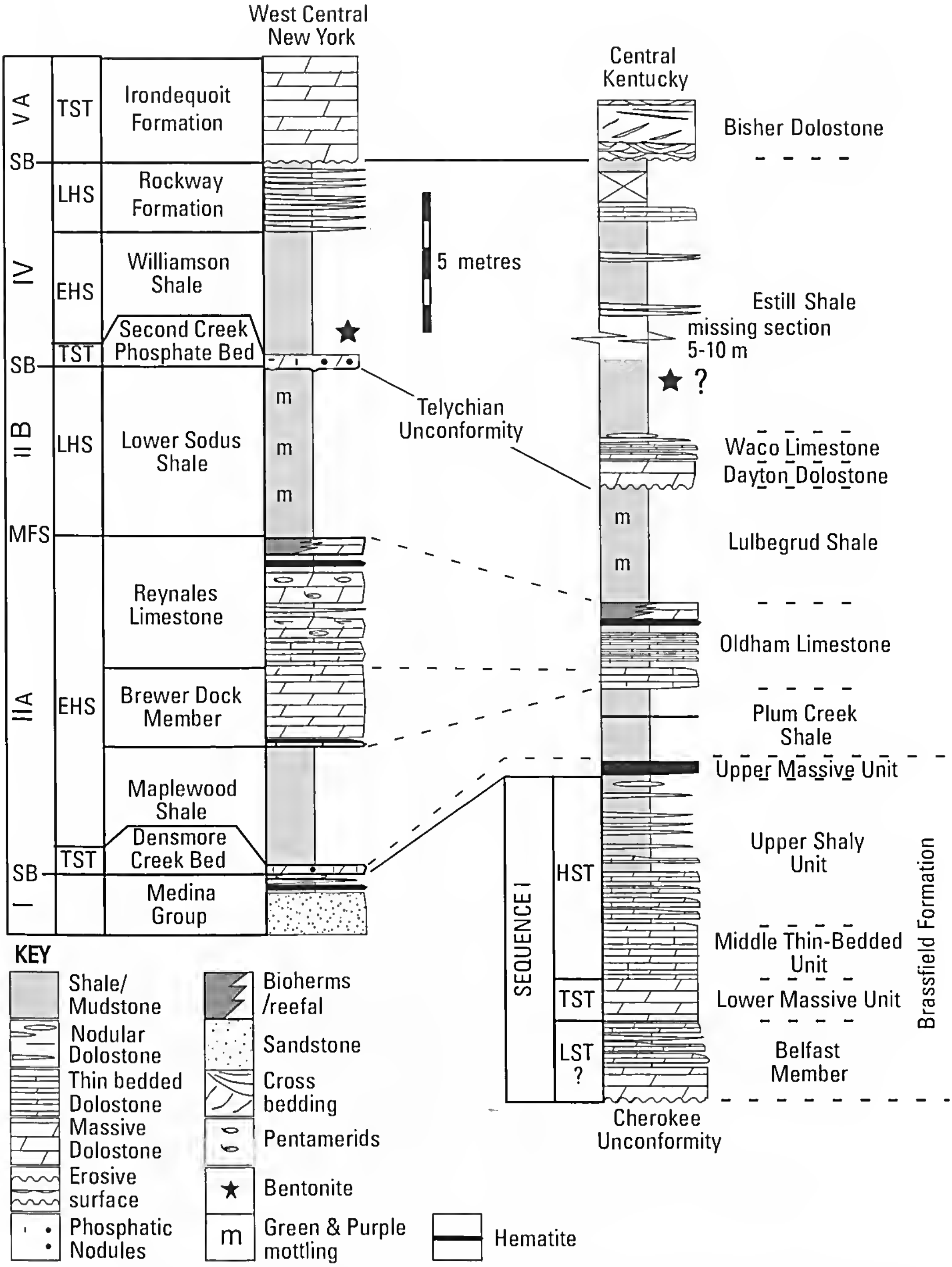

Fig 9. Comparison of Llandovery lithostratigraphic succession and inferred sequence stratigraphy in central New York State (vicinity of Rochester, NY) and central Kentucky/ southern Ohio. Sequence stratigraphic abbreviations as in Fig. 6.

Also included within sequence S-II in Ohio are the overlying Oldham Limestone and Lulbegrud Shale, which have been tentatively correlated with the Reynales Limestone and Sodus Shale of the classic New York section (Fig. 9; Lukasik 1988; Brett et al. 1990, 1998).

The Oldham Limestone comprises about 3–4 m of dolomitic wacke- and packstones, bearing a moderately diverse fauna. This limestone is dated as mid Llandovery Aeronian (C1–C2) age on the basis of conodonts (Kleffner 1990) and the brachiopod *Microcardinalia triplesiana* (formerly *Stricklandia triplesiana*; Berry & Boucot 1970). Ferruginous limestone below this bed may record a discontinuity, perhaps associated with the Sterling Station Iron Ore in the New York Clinton.

The Lulbegrud Shale is also about 3–4 m thick and comprises largely barren, greenish grey shale. This unit is poorly dated. Huddle (1967) reported *Neospathognathodus celloni* Zone conodonts from this unit suggesting a middle Telychian (C5) age, as in the Sodus Shale of New York (Fig.9). Together, the Oldham Limestone and Lulbegrud Shale may represent the TST and HST, respectively, of a small-scale (fourth order) sequence.

Sequence S-IV In Ohio the Lulbegrud Shale, Oldham Limestone, and Plum Creek Shale are successively truncated to the northwest and overstepped by the Dayton Dolostone, a distinctive, thin, highly bioturbated glauconitic carbonate (Lukasik 1988; Fig. 10). In central Kentucky the Dayton interval is represented by the compact, basal, 30–60 cm, dolomitic limestone bed of the Waco Limestone Member (Figs. 9,10). This bed is gradationally overlain by up to 2 m of thin bedded, highly fossiliferous limestone and shale near Irvine, Kentucky. Together, these beds of the Waco record a diverse and abundant fauna, especially rich in rugose and tabulate corals, including *Strombodes*, *Arachnophyllum*, *Chonophyllum*, and *Polyorophe*, some of which resemble those found in the late Llandovery of Ontario as well as in the Wenlock of England and Gotland (Foerste 1906).

The Dayton Dolostone has been dated as late Llandovery (mid-Telychian, N. celloni Zone) on the basis of conodonts (Kleffner 1990). The Dayton is thus approximately coeval with the Merritton Limestone and upper Fossil Hill Dolostone, which similarly overstep strata of sequence S-II in the Bruce Peninsula area of southern Ontario, Canada (Stott & Von Bitter 1999; Fig.7). Correlation of the Waco-Dayton with the upper Fossil Hill is further supported by similarities in the coral fauna. This interval may correlate with the Westmoreland Iron Ore and equivalent Second Creek Phosphate bed in New York (Lin & Brett 1989; Brett et al. 1990). The Dayton-Waco carbonates are, correspondingly, interpreted as the TST of sequence S-IV; with sequence S-III (Sauquoit Shale), as well as upper parts of Sequence S-II (Wolcott Limestone), removed beneath the basal unconformity, as in western New York and Ontario (Lin & Brett 1988; Brett et al. 1990).

Brett et al. (1990) inferred that the sub-Dayton unconformity of central Ohio and the sub-Merritton-Fossil Hill unconformity in Ontario are local manifestations of the same regional unconformity. It probably represents a minor episode of uplift and erosion along the Algonquin Arch, which was evidently active during the medial Silurian. Goodman & Brett (1994) suggested that this activity may reflect an isostatic response to thrust loading during early phases of the Salinic Orogeny (Fig. 3).

The HST of the fourth Silurian sequence (S-IV) is represented by the 10 to 20 m Estill Shale (a member of the Crab Orchard Formation in Kentucky terminology), which overlies the Dayton Limestone in the Dayton, Ohio region and the equivalent Waco Limestone in central Kentucky. (Figs.7, 9).

In southern Ohio and northeastern Kentucky the Dayton-Waco carbonates appear to be absent and a thick shale (perhaps as much as 45 m thick in West Union, Ohio; Foerste 1906), mapped as the "Estill Shale", may actually be equivalent to both the Estill (*sensu stricto*) and the underlying Lulbegrud Shale (Fig. 11). Lower and upper units are separated by a subtle but regionally angular unconformity. The "lower Estill Shale" consists of purplish shales and contains an ostracode and conodont fauna suggestive of a mid Telychian age; this could correlate with either the upper Sodus Shale (sequence S-II) or the Sauquoit Shale (sequence S-III) of the New York succession (Brett et al. 1990, 1998). At the roadcut on the AA Highway near Charters, Kentucky (Fig. 11), a subtle but slightly angular discordance appears between the lower purplish shales and the overlying greenish-grey shales and siltstones of the upper Estill Formation (Mason et al. 1992a). At most, a thin transgressive lag deposit occurs at the base of sequence S-IV.

The upper Estill Shale is assigned a latest Llandovery (late Telychian) age on the basis of graptolites of the *Monograptus cf. M. clintonensis* Zone and conodonts of the *Pterospathodus amor-*

phognathoides Zone (Rexroad 1970; Kleffner 1987). The lower five meter interval of shale and thin, fossiliferous siltstones appears to correlate directly with the uppermost Rose Hill Shale of the Appalachian Basin and with the Williamson- Willowvale shales (sequence S-IV) of the standard New York section (Fig. 9). This represents the highest stand of relative sea level during the Silurian in eastern North America and appears to reflect a global eustatic highstand (Johnson 1996; Johnson et al. 1998).

The uppermost Estill dolomitic siltstone unit (previously assigned to the overlying Bisher Formation; Potter et al. 1991; Mason et al. 1992a,b), which is regionally removed under the S-V unconformity at the base of the Bisher Dolostone, comprises thin- to medium-bedded dolomitic and somewhat fossiliferous carbonates, interpreted as tempestites (Aigner 1985; Mason et al. 1992a) and greenish-grey shales. This dolomitic siltstone appears to correlate directly with the Rockway Formation of Ontario and New York State and with the lower Keefer Sandstone or sandy uppermost Rose Hill Formation in Pennsylvania (late highstand of sequence S-IV; subsequence S-IVB; Figs. 6, 7, 9). To the northwest, near Dayton, Ohio, the Estill appears to grade into rhythmically bedded shale and dolomitic carbonate of the lower shale member of the Osgood Formation (Fig. 10).

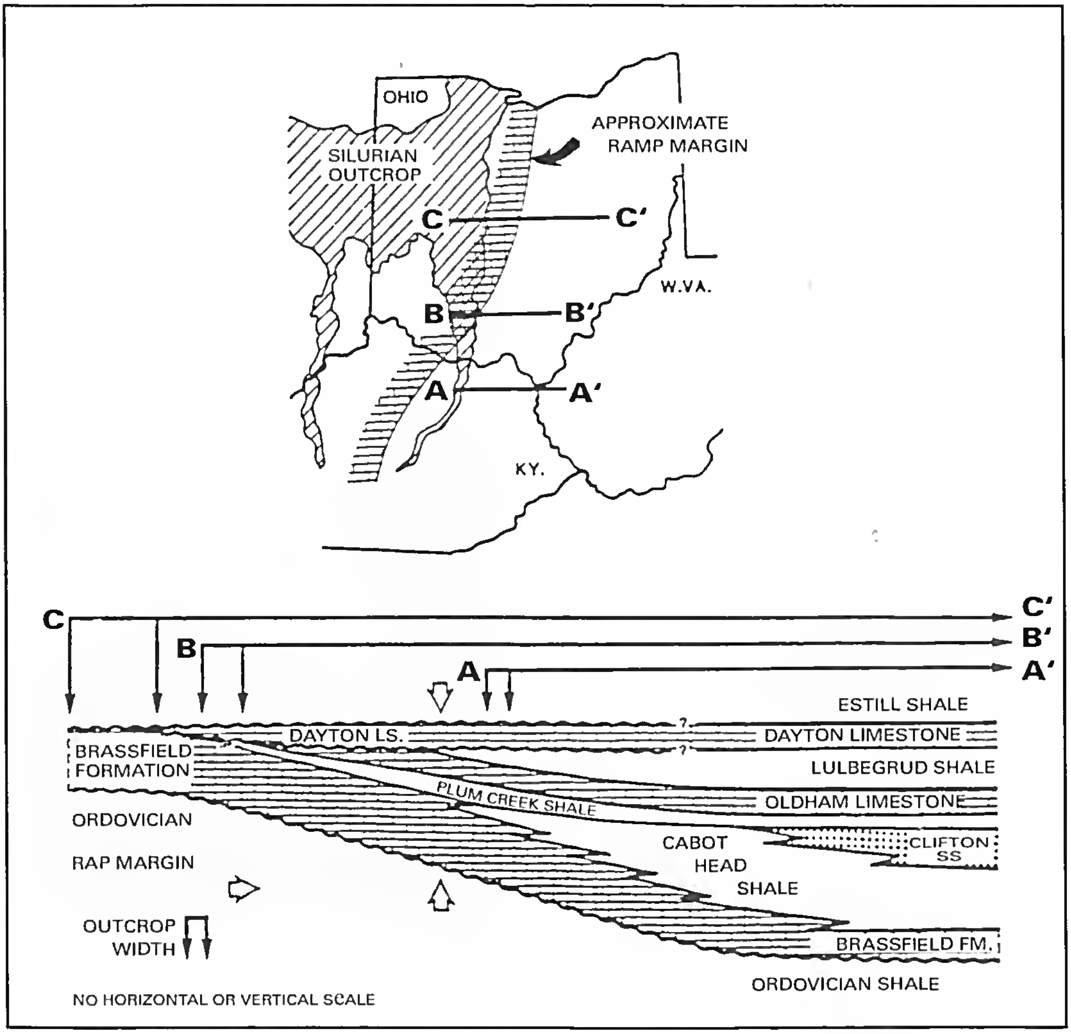

Fig 10. Regional cross sections of Silurian strata through south-central Ohio and northern Kentucky. Note the regional truncation of units along a proto-Findlay Arch (northwest or left side of cross section) below a major unconformity beneath the Dayton Limestone. Adapted from Lukasik (1988).

Also, probable K-bentonites have been found in this interval, which may correlate with beds in the Osgood Shale on western flank of the Cincinnati Arch (Ray & Brett 2001; Brett & Ray 2001). These ash beds may also correlate with K-bentonites found in the upper Llandovery of the southern Appalachians (Huff et al. 1997). Work on these beds is preliminary but appears promising. In particular a 1–3 cm greenish clay bed low in the Osgood Shale at Fairborn, Ohio appears to be traceable into outcrops of the Osgood in southern Indiana. It may also correspond to a bentonite reported from the upper Estill Shale at Charters, Kentucky (Mason et al. 1992a) and one or more thin yellowish weathering clay beds (probable K-bentonites) in the lower Williamson Shale at Rochester, NY (Brett et al. 1994).

Sequence S-V A very distinct sequence boundary at the base of the Bisher Dolostone separates overlying Sequence S-V from the underlying Estill Shale. At this surface, the uppermost Estill dolomitic siltstones and shales appear to be regionally truncated along a series of outcrops near Vanceburg, Kentucky (Figs. 7, 9, 12).

Sequence S-V shows a well-defined transgressive systems tract, recorded in crinoidal dolomitic packstones and grainstones, rich in the brachiopod *Whitfieldella oblata*, now assigned to the lower unit of the as-yet undifferentiated Bisher Formation (Figs. 12–15). This interval has yielded conodonts indicating a *Spathognathodus ramliformis* Zone age (Rexroad 1970; Berry & Boucot 1970; Kleffner 1989, 1991); this bed is aligned with the similarly dated crinoidal grainstones of the Irondequoit Formation in western New York (Rexroad & Rickard 1965). The top of the lower Bisher unit is thus interpreted as a major flooding surface corresponding to the upper glauconitic condensed bed of the Irondequoit Limestone in western New York. This is sharply overlain by a thin shaly HST interval, termed Massie Shale in the Dayton, Ohio area, apparently correlative with the Rochester Shale in the Appalachian Basin (Figs. 12, 13). This interval also correlates with the thin upper shale unit of the Osgood Member in Indiana, which has yielded a fauna of brachiopods, bryozoans and echinoderms very similar to those of the Rochester Shale in New York (Frest et al. 1999). No more than a half-meter of shales and thin calcisiltites occurs at this level in Kentucky. However, to the north, near Hillsboro, Ohio, a succession of nearly three meters of typical Massie (="Rochester") Shale overlies the basal grainstones of the Bisher Dolostone. The succession thins again toward Dayton, Ohio (Figs.13, 14).

A very interesting laminated dolostone bed up to 1 m thick overlies the "Massie" shale interval. Locally, as near Peebles, Ohio, this bed shows strong ball-and-pillow style deformation. The interval very closely resembles the DeCew Dolostone, which sharply overlies the Rochester Shale in western New York and Ontario (Figs. 12, 15). In all of its outcrops the DeCew is similarly heavily deformed. We suggest that the contorted beds in the upper Bisher/Massie units and the DeCew Dolostone represent coeval, sandy, detrital carbonate facies associated with a forced regression; i.e., they represent the falling stage systems tract of sequence V, and their typically sharp base indicates a forced regression surface. Moreover, the occurrence of deformation in this interval over a vast region suggests that these beds record extremely large seismic shocks. Pope et al. (1997) and McLaughlin & Brett (2004) documented similar very widespread deformation in similar regressive detrital carbonates in the Ordovician of Kentucky. We suggest that these widespread deformed beds record not only appropriate ("deformation-prone") facies, but also a "trigger" provided by seismic shocks. Such seismites may provide very useful regional event stratigraphic markers (Pope et al., 1997; McLaughlin and Brett, 2004).

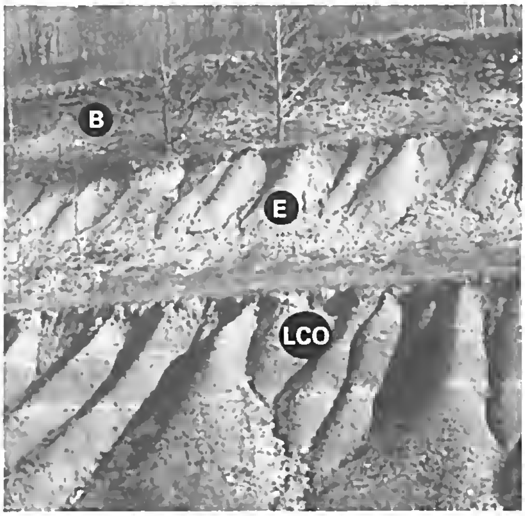

Fig 11. Roadcut section along AA Highway (KY Rte. 9/10) at Charters, Lewis Co., KY showing Crab Orchard Shale overlain by Bisher Dolostone (B), near top off view. Lower Crab Orchard beds are maroon shales with thin siltstones and possible K-bentonite showing apparent slight discordance with overlying lighter greenish grey (Estill) shale. Height of cut is approximately 25 m.

Sequence S-VI. The remainder of the Bisher Formation contains a complex facies mosaic, the details of which are somewhat obscured by dolomitization (Mason et al. 1992b). A cryptic, but important, sequence boundary occurs above the Massie calcisiltite and shale interval. This sequence boundary appears to correlate with the base of the Lockport Group and the base of the McKenzie

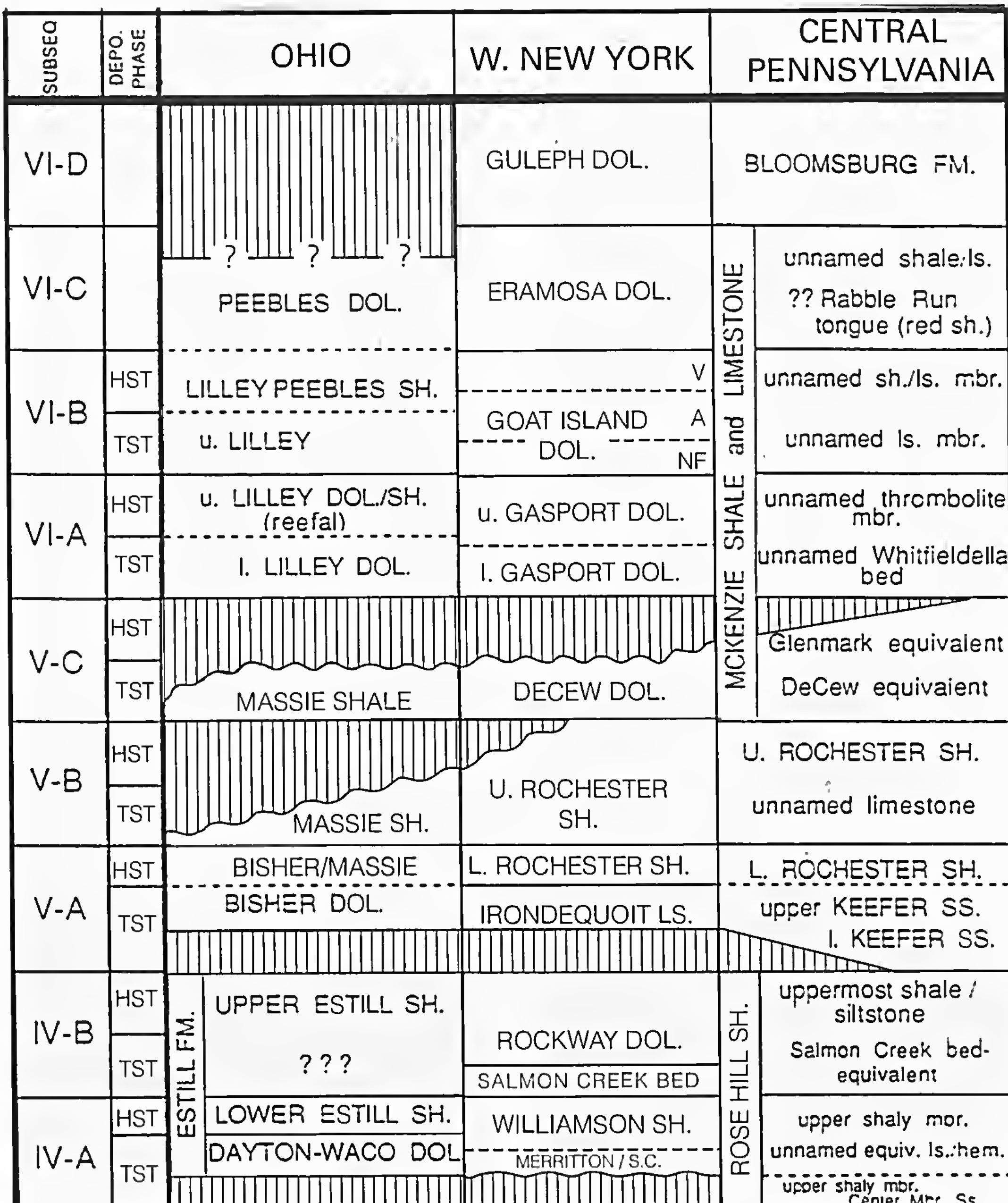

Fig 12. Summary of correlation of upper Llandovery-Wenlock units in central Ohio, New York State/Ontario, and Pennsylvania. Abbreviations for members of Goat Island Formation: NF: Niagara Falls (massive dolostone); A: Ancaster (cherty dolostone) Member; Member; V: Vinemount (shaly dolostone) Member; SC: Second Creek phosphate bed of Williamson shale; terminology of Brett et al. (1995).

Formation in Pennsylvania and Maryland and represents the base of sequence S-VI (Figs. 8, 12). This interval is represented by hummocky to herringbone cross-stratified, crinoidal dolostones, assigned to the upper Bisher Formation in Kentucky and to the Bisher or lower Lilly Formation in Adams County, Ohio (Figs. 14, 15; Ausich 1987; Kleffner & Ausich 1988; Kleffner 1990). Local abrupt changes in thickness and facies within this succession are typical (Mason et al. 1992a,b) and may represent the development of a series of skeletal megashoals and intershoal areas during this part of Wenlock time (Pratt & Miall 1993). The top of this succession contains a distinctive, poorly bedded interval that appears as a series of mounds or blocks of dolomicrite surrounded by poorly bedded dolomitic mudstones. This interval has been interpreted as a collapse breccia associated with karstification during the Devonian because it lies just below the Kaskaskia unconformity in several locations. However, close examination of the mounds revealed the presence of heavily dolomitized corals, stromatoporoids and crinoid holdfasts. Thus, we interpret the mounds as bioherms (Fig. 14). This interval thus appears to be a continuation of the Gasport biohermal interval, widely distributed in the Appalachian Basin in western New York and Ontario (Crowley 1973; Smosna & Patchen 1992; Fig. 15). At Hillsboro, Ohio it appears that this interval passes laterally into a greenish shaly dolostone and shale interval that we would correlate with the upper or Pekin Member of the Gasport Formation (Brett et al. 1990). Just why biohermal buildups are so prolific at this horizon is poorly understood but we suggest a combination of low siliciclastic sedimentation during an episode of gradual sea level rise (Crowley 1973; Smosna & Patchen 1992).

The overlying upper Lilly Dolostone succession of southern Ohio comprises massive crinoidal dolostone, locally with chert nodules; this interval appears to grade laterally to the northwest into the Cedarville Dolostone near Dayton, Ohio (Fig. 14). This interval has yielded conodonts of the *Ozarkodina saggita rhenana* Zone (Kleffner, 1990); it is lithologically similar to the correlative lower Goat Island Dolostone (Niagara Falls, and Ancaster cherty members of Brett et al. 1995) in western New York and Ontario. A shaly interval identified as the "Lilly-Peebles transition", in south-central Ohio (Ausich 1987; Kleffner and Ausich, 1988) records a distinct deepening event. We tentatively correlate this interval to shaly dolostone and shale of the Vinemount Member in Ontario and western New York (Brett et al. 1995), and possibly to the Waldron Shale of Indiana and Kentucky. A preponderance of shale during this interval throughout much of eastern North America, may suggest a deepening and influx of siliciclastics associated with the second tectophase of the Salinic Orogeny (Ettensohn & Brett 1998); alternatively it may record a widespread late Wenlock eustatic highstand (Johnson et al. 1998).

The Peebles Dolostone, the highest Silurian unit present in south-central Ohio, consists of massive vuggy dolostone that may relate to the Eramosa Dolostone of Ontario. The contact of this unit on the underlying shales is sharp, and probably represents the VII sequence boundary (Brett et al. 1995). However, the biostratigraphy of the Lilly-Peebles and Peebles interval requires further study to test these correlations.

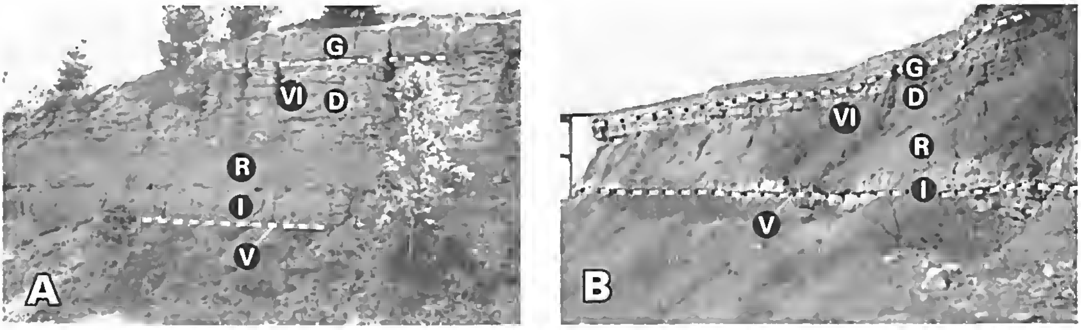

Fig 13. Comparative stratigraphy of sequences S-V and S-VI in Ohio and New York. A) section of upper Estill and Bisher formations;Rochester Shale equivalent R is about 3 m thick; roadcut along US Rte. 62 just south of Hillsboro, Highland Co., Ohio. Note comparable succession of units in Ohio correlative with those of western New York. B) Upper Clinton and Lockport Groups; Rochester Shale is approximately 20 m thick. Niagara Gorge near Lewiston, Niagara Co., NY. Symbols for New York units and their probable equivalents in Ohio include: I: Irondequoit Limestone; R: Rochester Shale; D: DeCew Dolostone; G: Gasport Limestone. Two sequence boundaries are present here marked V and VI (note arrows).

The upper Lilly to Peebles interval has been largely removed by Devonian erosion in northern Kentucky. Toward Dayton, however, higher Silurian units, as well as Middle Devonian beds emerge as this unconformity becomes less prominent. In the southeastern part of the study area grey to black pyritic shales of the Upper Devonian (Famennian) are juxtaposed directly upon eroded Silurian carbonates (see Fuentes et al. 2001). The unconformity typically displays a small amount of relief and may be overlain by a thin lag deposit of dark bone and conodont-rich pyritic to phosphatic limestone. Corrosion and some dissolution of the underlying Silurian carbonates is typical.

Figure 14 illustrates a northwest-southeast correlated cross section based upon four major outcrops at Fairborn, Ohio to Herron Hill, Kentucky; terminology follows Ausich (1987) and Kleffner & Ausich (1988). A similar succession of units is present over this region, although similarities have been masked by different terminology and offset of contacts: A) ("Laurel"-lower Bisher Fm.) a lower compact, massive crinoidal brachiopod-rich limestone/dolostone rests sharply on shales or shaly dolostones, and is overlain by B) (Massie Shale) soft, medium to dark grey shales and/or argillaceous dolostones, capped, in turn, by C) (part of Massie Shale) laminated to hummocky cross stratified dolomitic siltstone or silty-sandy dolostone typically with internal deformation. The latter is sharply overlain by D) (Euphemia, upper Bisher Fm.) massive, cross bedded, sandy crinoidal dolostone which grades upward into E) (Springfield-upper Bisher Fm.) thin bedded dolostones with dolomitic shale

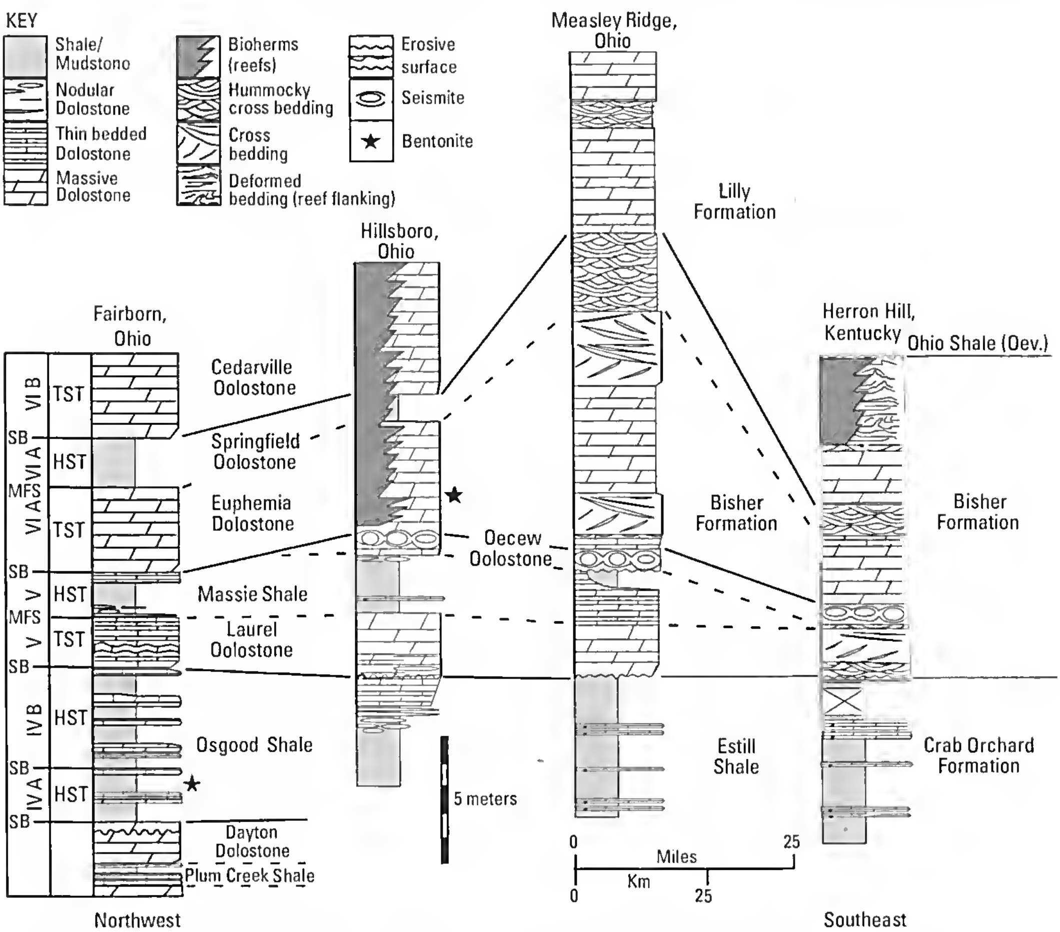

Fig 14. Correlated stratigraphic columns along NW-SE cross-section from Fairborn Quarry just SE of Dayton, Ohio to Herron Hill, Lewis Co., Kentucky. Approximate position of cross section shown in Figure 2. Note comparison of New York-Ontario terminology shown in Fig. 15. Sequence stratigraphic abbreviations as in Fig. 6.

partings, sharply overlain by F) (Cedarville, Lilly Fm.) more massive crinoidal dolostones with local stromatoporoid biostromes and micritic mounds; G) (Lilly, upper Bisher Fm.) local cherty bioturbated dolomicrite; and, finally, H) (Lilly-Peebles transition) shaly dolostone and dolomitic shales, which locally contain bioherms.

The successions in Ohio and Kentucky can be correlated unit for unit with those of the latest Llandovery to Wenlock succession of New York and Ontario, Canada (Figs. 12, 15), as follows: Unit A: Irondequoit Limestone; Unit B) Rochester Shale (partially truncated by erosion to the west in Ontario); Unit C: DeCew Dolostone (a possible widespread seismite); Unit D: lower Gasport Limestone (Gothic Hill Member), crinoidal dolomitic grainstone); Unit E: upper Gasport (Pekin Member), thinly bedded dolostones and bioherms; Unit F: lower Goat Island Formation (Niagara Falls Member), massive crinoidal dolostone; Unit G: middle Goat Island (Ancaster Member) medium to thin bedded cherty dolomicrite; and Unit H: upper Goat Island (Vinemount Member), dolomitic shale and shaly dolostone. In turn, these units represent components (mainly systems tracts) of regionally widespread depositional sequences and subsequences: Unit A: TST of S-V; Unit B: HST of S-V; Unit C: FSST of subsequence S-V (and base of a subsequence); Unit D TST of subsequence S-VIA; Unit E: HST of S-VIA; Units F, G, TST of S-VIB; and Unit H: HST of S-VIB (Fig. 12; see Brett et al. 1990, for definition and discussion of these sequences).

SUMMARY DISCUSSION

Despite a multiplicity of names applied to medial Silurian units in different regions along the eastern to northern flank of the Cincinnati, this area displays the same basic succession of units and indeed, this succession can be matched rather closely with the coeval interval in the Appalachian Basin. The lateral persistence of sequences and their bounding surfaces over much of northeastern to central North America strongly suggests an allocyclic, probably eustatic sea level control on the development of these sequences. However, the local expression of the sequences and their bounding surfaces was modified by far-field tectonics, notably gentle uplift and migration of the Findlay-Algonquin Arch, influenced by lithospheric flexure (Beaumont et al. 1988).

The medial Silurian succession along the eastern flank of the Cincinnati Arch in south-central Ohio, is most comparable to that exposed along the Niagara Escarpment in southern Ontario, Canada and western New York. The similarities of facies and thickness patterns probably reflect the fact that these widely separated areas lay more or less along the same NE-SW trending depositional strike belt.

During Wenlock time the Findlay-Algonquin Arch system was oriented northeast-southwest from near Hamilton, Ontario to southwestern Ohio (Figs. 2, 10). Both the outcrops in southern Ontario and those of south central Ohio represent facies deposited to the southeast of the arch. The Brassfield Dolostone maintains similar thickness and only minor facies change across this region, suggesting that no major positive feature was present in early Llandovery time. However, regional cut out of Sequences S-I to S-III toward the northwest in both New York-southern Ontario and south central Ohio reflects erosional truncation of units along the arch, a probable forebulge that became uplifted during later Llandovery time (Lukasik 1988; Brett et al. 1990). This cut out appears to occur beneath a widespread glauconitic-bioturbated dolostone, the Merritton Dolostone of Ontario and equivalent Dayton Formation in Ohio. Likewise, the thinning and increased carbonate content of the Estill-Osgood interval and sharpening of the contacts from Hillsboro northwest to Fairborn, Ohio reflects a generally positive area in the Findlay-Algonquin Arch (northeast branch of Cincinnati Arch). However, the thickness of the Estill Shale in central Ohio and northern Kentucky more resembles that of the Williamson-Willowvale interval in central New York State, suggesting an abrupt shift in the angle of orientation of the basin axis in late Telychian time (cf. Ettensohn & Brett 1998; Ettensohn 2004). This change in geometry will be discussed more fully in a forthcoming paper.

Not so readily explained is the apparent condensation of sequences S-V and S-VI and the cut out of unit D (Massie-Rochester Shale) to the southeast in northern Kentucky. This suggests the development of a secondary arch to the southeast of the Cincinnati or Findlay arch. In later Silurian and Devonian time this southeastern area becomes the region of maximum truncation. Thus, for example, in areas to the southeast of Vanceburg, Upper Devonian black shales rest successively upon the Bisher, Estill, Brassfield and finally on Upper Ordovician formations. This effect has been attributed to the rise of

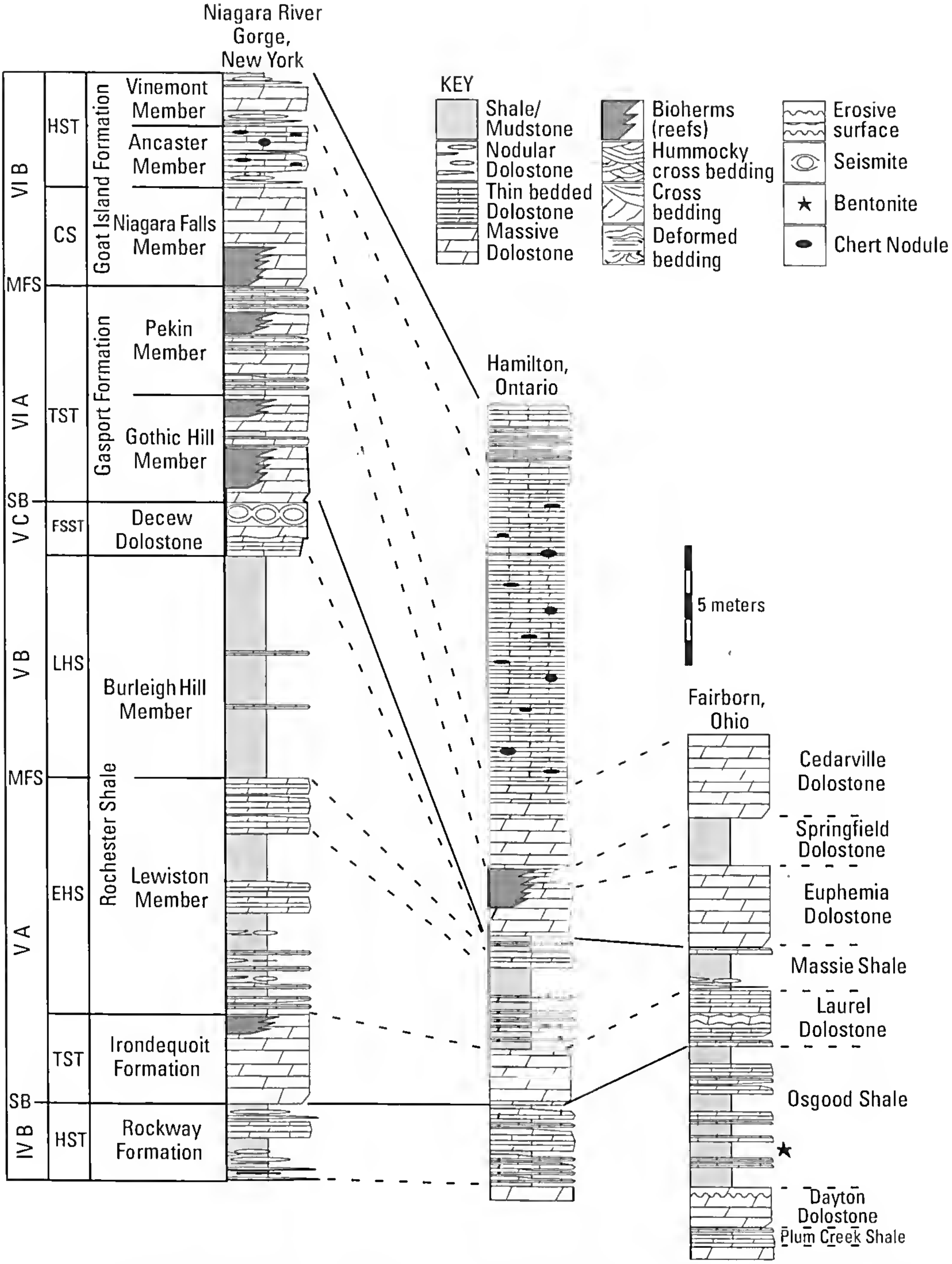

Fig 15. Correlation of late Llandovery to Wenlock stratigraphy of Niagara Gorge, New York, Hamilton, Ontario, and Dayton, Ohio. Sequence stratigraphic abbreviations as in Fig. 6.

the "Cincinnati Arch" during Siluro-Devonian time, although, in fact, it is clear that this positive area was positioned well to the southeast of the present Cincinnati Arch. In any case, it is now apparent that arching in the southeast must have commenced during Wenlock time. The Estill Shale (latest Llandovery) does not appear to have been strongly affected by this arching and indeed thickens to the southeast. Conversely, the Massie-Rochester Shale is largely truncated by the sub-sequence S-VC and/or basal S-VI erosion surfaces in the vicinity of Vanceburg, Kentucky. It is not clear at this time what the exact orientation of the northern Kentucky positive area was, nor how far northward this arch extended. It does not appear in the western New York or Pennsylvania outcrop belts. Further study of subsurface relationships will be needed to clarify these relationships, but these will be aided by the extension of a detailed sequence and event stratigraphic framework.

Finally, both the occurrence of an extremely widespread seismite (DeCew horizon) and newly discovered K-bentonites indicates both seismic and volcanic activity within or at the periphery of the Appalachian foreland basin. This evidence, together with evidence for restructuring and/or migration of arches (forebulges; Beaumont et al. 1988; Ettensohn & Brett 1998; Ettensohn 2004) during the latest Llandovery to Wenlock, indicates renewed active tectonism within the medial Silurian as previously postulated (Goodman & Brett 1994; Ettensohn & Brett 1998).

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REFERENCES

Aigner, T., 1985. *Storm Depositional Systems: Dynamic Stratigraphy in Modern and Ancient Shallow Marine Sequences, Lecture Notes in the Earth Sciences 3*. Springer, Berlin, 174 pp.

Ausich, W.I., 1987. John Bryan State Park: Silurian Stratigraphy. *Geological Society of America DNAG Centennial Field Guide, North Central Section*, p. 419–422.

Beaumont, C., Quinlan, G. & Hamilton, z, J., 1988. Orogeny and stratigraphy: Numerical models of the Paleozoic in the eastern interior of North America. *Tectonics* 7: 389–416.

Berry, W.B.N. & Boucot, A.J., 1970. Correlation of the North American Silurian rocks. *Geological Society of America Special Paper* 102: 1–289.

Brenchley, P.J., 2004. End Ordovician glaciation. In *The Great Ordovician Biodiversification Event*. B.D. Webby, F. Paris, M.L. Droser & I.G. Percival, eds, Columbia University Press, New York, 81–83

Brenchley, P.J., Marshall, J.D., Carden, G.A.F., Robertson, D.B.R., Long, D.G.F., Meidi, T., Hints, L. & Anderson, T.F. 1994. Bathymetric and isotopic evidence for a short-lived Late Ordovician glaciation in a greenhouse period. *Geology* 22: 295–298.

Brett, C.E., 1995. Sequence stratigraphy, biostratigraphy, and taphonomy in shallow marine environments. *Palaios* 10: 597–616.

Brett, C.E., 1998. Sequence stratigraphy, paleoecology, and evolution: Biotic clues and responses to sea-level fluctuations. *Palaios* 13: 241–262.

Brett, C.E., Baarli, B.G., Chowns, T., Cotter, E., Driese, S., Goodman, W. & Johnson, M.E., 1998. Early Silurian condensed horizons, ironstones, and sequence stratigraphy in the Appalachian foreland basin. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes*, E. Landing & M.E. Johnson, eds, New York State Museum Bulletin 491: 89–143.

Brett, C.E., Boucot, A.J. & Jones, B., 1993. Absolute depths of Silurian benthic assemblages. *Lethaia* 26: 25–40.

Brett, C.E., Goodman, W.M. & LoDuca, S.T., 1990. Sequences, cycles, and basin dynamics in the Silurian of the Appalachian foreland basin. *Sedimentary Geology* 69: 191–244.

Brett, C.E., Goodman, W.M. & LoDuca, S.T., 1994. Ordovician and Silurian strata in the Genesee Valley area: Sequences, cycles, and

facies: *New York State Geological Association Field Trip Guidebook.* 66th Annual Meeting, Rochester, New York 381–442.

BRETT, C. E. & RAY, D.C., 2001. Sequence and event stratigraphy of the Medial Silurian of Eastern North America: comparisons of Appalachian Basin and Cincinnati Arch successions. *Geological Society of America. Abstracts with Programs* 33 (1): A-16.

BRETT, C.E., TEPPER, D.H., GOODMAN, W.M., LODUCA, S.T. & LIN, B.Y., 1995. Revised stratigraphy and correlation of the Niagaran Provincial Series (Medina, Clinton, and Lockport groups) in the type area of western New York. *U.S. Geological Survey Bulletin* 2086: 1–66.

CATUNEANU, O., 2002. Sequence stratigraphy of clastic systems: concepts, merits, and pitfalls. *Journal of African Earth Sciences* 35: 1–43.

CROWLEY, D. J., 1973. Middle Silurian patch reefs in the Gasport Member (Lockport Formation), New York. *American Association of Petroleum Geologists Bulletin* 57: 283–300.

COE, A.L. & CHURCH, K.D., 2003. Sequence stratigraphy. In *The Sedimentary Record of Sea-Level Change*, A.L. Coe, ed, Cambridge University Press, 57–98.

DENNISON, J.M. & ETTENSOHN, F.M., eds, 1994. Tectonic and Eustatic Controls on Sedimentary Cycles. *Society for Economic Paleontologists and Mineralogists, Concepts in Sedimentology and Paleontology* 4: 181–201.

DENNISON, J.M., & HEAD, J.M., 1975. Sea-level variations interpreted from the Appalachian Basin Silurian and Devonian. *American Journal of Science* 275: 1089–

EMERY, D. & MYERS, K.J., eds., 1996. *Sequence Stratigraphy.* Blackwell, Oxford, 297pp.

ETTENSOHN, F.R., 1991. Flexural interpretation of relationships between Ordovician tectonism and stratigraphic sequences, central and southern Appalachians, U.S.A. In *Advances in Ordovician Geology*, C.R. Barnes & S.H. Williams, eds, *Geological Survey of Canada Paper* 90-9, 213–224.

ETTENSOHN, F.R., 1992a. *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy. Ohio Division of Geological Survey, Miscellaneous Report* 5, 184 pp.

ETTENSOHN, F.R., 1992b. Basic flexural models. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, *Ohio Division of Geological Survey, Miscellaneous Report* 5, 9–12.

ETTENSOHN, F.R., 1992c. General Ordovician paleogeographic and tectonic framework for Kentucky. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, *Ohio Division of Geological Survey, Miscellaneous Report* 5, 19–21.

ETTENSOHN, F.R., 1992d. Upper Ordovician-Lower Silurian rocks at Cabin Creek, northeastern Kentucky. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, *Ohio Division of Geological Survey, Miscellaneous Report* 5, 159–164.

ETTENSOHN, F.R., 2004. Modeling the nature and development of major Paleozoic clastic wedges in the Appalachian Basin, USA. *Journal of Geodynamics* 37: 657–681.

ETTENSOHN, F.R. & BRETT, C.E., 1998. Tectonic components in Silurian cyclicity: Examples from the Appalachian Basin and global implications. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes* E. Landing, E. & M.E. Johnson, eds, *New York State Museum Bulletin* 491: 145–162.

Ettensohn, F.R. & Brett, C.E., 2002. Stratigraphic evidence from the Appalachian Basin for continuation of the Taconian Orogeny into Silurian time. In *Taconic Convergence: Orogen, Foreland Basin and Craton*, C.E. Mitchell & R. Jacobi, eds, *Physics and Chemistry of the Earth* 27, 279–288.

ETTENSOHN, F.R. & PASHIN, J.C., 1992. A brief structural framework of Kentucky. In *Changing Interpretations of Kentucky Geology: Layer Cake, Facies, Flexure, and Eustasy*, F.R. Ettensohn, ed, *Ohio Division of Geological Survey, Miscellaneous Report* 5, 6–9.

FOERSTE, A.F., 1906. The Silurian, Devonian, and Irvine formations in east-central Kentucky. *Kentucky Geological Survey Bulletin* 7: 369 pp.

FOERSTE, A.F., 1935. Correlation of Silurian formations in southwestern Ohio and southeastern Indian, Kentucky, and western Tennessee. *Bulletin, Scientific Laboratory, Denison University* 30: 119–205.

FREST, T.J., BRETT, C.E. & WITZKE, B., 1999. Caradocian to Gedinnian echinoderm associations of central and eastern North America. In: *Palaeocommunity Analysis: A Silurian-Lower Devonian Example*, A.J. Boucot & J.D. Lawson, eds, Cambridge University Press, 638–783.

FUENTES, S., OVER, D.J. & BRETT, C. E., 2001. Conodont biostratigraphy of "Olentangy" Shale in northeastern Kentucky. In: Sequence, Cycle, and Event Stratigraphy of Upper Ordovician and Silurian Strata of the Cincinnati Arch Region. T.J. Algeo & C.E. Brett, eds, *Kentucky Geological Survey Guidebook* 1, Kentucky Geological Survey, Lexington, Kentucky, p. 136–140.

GOODMAN, W.M. & BRETT, C.E., 1994. Tectonic vs. eustatic controls on the stratigraphic architecture of the Silurian, northern Appalachian Basin. In *Tectonic and Eustatic Controls on Sedimentary Cycles: Society of Economic Paleontologists and Mineralogists, Concepts in Sedimentology and Paleontology*, J.M. Dennison & F.M. Ettensohn, eds, 4: 147–169.

GORDON, L.A. & ETTENSOHN, F.R., 1984. Stratigraphy, depositional environments, and regional dolomitization of the Brassfield Formation (Llandoverian) in east-central Kentucky. *Southeastern Geology* 25: 101–115.

GRAHN, Y. & CAPUTO, M., 1992. Early Silurian glaciation in Brazil. *Palaeogeography, Palaeoclimatology, Palaeoecology* 99: 9–15.

HAQ, B.U., HARDENBOL, J. &VAIL, P.R., 1987. Chronology of fluctuating sea-levels since the Triassic. *Science* 235: 1153–1165.

HOLLAND, S.M., 1993. Sequence stratigraphy of a carbonate-clastic ramp: The Cincinnatian Series (Upper Ordovician) in its type area. *Geological Society of America Bulletin* 105: 306–322.

HOLLAND, S. M., 1998. Sequence stratigraphy of the Cincinnatian Series (Upper Ordovician, Cincinnati, Ohio, region). In *Sampling the Layer Cake That Isn't: The Stratigraphy and Paleontology of the Type-Cincinnatian*, R.A. Davis & R.J. Cuffey, eds. *Ohio Division of Geological Survey, Guidebook* No. 13, 135–151.

HUDDLE, J.W., 1967. Silurian conodonts from Kentucky: *U.S. Geological Survey Professional Paper, Geological Survey Research*, 1967, 377 pp.

HUFF, W.D., MORGAN, D.J. & RUNDLE, C.C., 1997. Silurian K-bentonites of the Welsh borderlands: Geochemistry, mineralogy and K-Ar ages of illitization. *BGS Technical Report WG/96/45 Mineralogy and Petrology Series* 25pp.

JOHNSON, M.E., 1996. Stable cratonic sequences and a standard for Silurian eustasy. In *Paleozoic Sequence Stratigraphy: Views from the North American Craton*, B.J. Witzke, G.A. Ludvigson & J.E. Day, eds, *Geological Society of America Special Paper* 306, 203–211.

JOHNSON, M.E., RONG, J.Y. & KERSHAW, S., 1998. Calibrating Silurian eustasy by erosion and burial of coastal paleotopography. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes*, E. Landing & M.E. Johnson, eds, *New York State Museum Bulletin* 491: 3–13.

KALJO, D., JOHNSON, M.E., KIIPLI, T. & MARTMA, T., 1998. Correlation of carbon isotope events and environmental cyclicity in the East-Baltic Silurian. In *Silurian Cycles: Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic, and Tectonic Changes*, E. Landing & M.E. Johnson, eds, *New York State Museum Bulletin* 491, p. 297–312.

KIDWELL, S.M., 1991. The stratigraphy of shell concentrations. In *Taphonomy: Releasing the Data Locked in the Fossil Record*, P.A. Allison & D.E.G. Briggs, eds, Plenum, New York, 211–290.

KLEFFNER, M.A., 1987. Conodonts of the Estill Shale and Bisher Formation (Silurian, southern Ohio): Biostratigraphy and distribution. *Ohio Journal of Science* 87: 78–89.

KLEFFNER, M.A., 1989. A conodont-based Silurian chronostratigraphy. *Geological Society of America Bulletin* 101: 904–912.

KLEFFNER, M.A., 1990. Wenlockian (Silurian) conodont biostratigraphy, depositional environments, and depositional history along the eastern flank of the Cincinnati Arch in southern Ohio. *Journal of Paleontology* 64: 319–328.

KLEFFNER, M.A. & AUSICH, W.I., 1988. Lower and Middle Silurian of the Eastern Flank of the

Cincinnati Arch and the Appalachian Basin Margin, Ohio. *Field Trip 1. Society of Economic Paleontologists and Mineralogists*, Fifth Midyear Meeting, Columbus, Ohio, 25.

LEBOLD, J.G., 2000. Quantitative analysis of epizoans on Silurian stromatoporoids within the Brassfield Formation. *Journal of Paleontology* 74: 394–403.

LIN, B.Y. & BRETT, C.E., 1987. Stratigraphy and disconformable contacts of the Williamson-Willowvale interval: revised correlations of the Late Llandoverian (Silurian) in New York State. *Northeastern Geology* 10: 241–253.

LODUCA, S.T. & BRETT, C. E., 1994. Revised stratigraphic and facies relationships of the lower part of the Clinton group (Middle Llandoverian) of western New York State. In *Studies in Stratigraphy and Paleontology in Honor of Donald W. Fisher*, E. Landing, ed, *New York State Museum Bulletin* 48(1): 161–182.

LUKASIK, D.M., 1988. Lithostratigraphy of Silurian rocks in southern Ohio and adjacent Kentucky. *Ph.D. dissertation (unpubl.)*, University of Cincinnati, 313 pp.

MASON, C.E., LIERMAN, R.T., ETTENSOHN, F.R. & PASHIN, J.C., 1992a. Tempestite lithofacies of the Bisher Dolostone and Crab Orchard Shale (Middle Silurian) along Kentucky State highway 546, northeastern Kentucky, Charters section. In *Changing Interpretations of Kentucky Geology: Layer-Cake, Facies, Flexure and Eustasy*, F.R. Ettensohn, ed, *Ohio Division of Geological Survey, Miscellaneous Report* 5, 153–155.

MASON, C.E., LIERMAN, R.T., ETTENSOHN, F.R., & PASHIN, J.C., 1992b. Sandbelt lithofacies of the Bisher Dolostone, the Crab Orchard Shale, the Upper Olentangy Shale, and the Huron Member of the Ohio Shale in northeastern Kentucky. In *Changing Interpretations of Kentucky Geology: Layer-Cake, Facies, Flexure and Eustasy*, F.R. Ettensohn, ed, *Ohio Division of Geological Survey, Miscellaneous Report* 5, 156–158.

MCLAUGHLIN, P.I. & BRETT, C.E., 2004. Eustatic and tectonic control on the distribution of marine seismites: examples from the Upper Ordovician of Kentucky, USA. *Sedimentary Geology* 168: 165–192.

MYERS, K.J. & MILTON, N.J., 1996. Concepts and principles. In *Sequence Stratigraphy*, D. Emery & K.J. Myers, eds, Oxford, Blackwell, 11–44

POPE, M.C., READ, J.F., BAMBACH, R. & HOFFMAN, H.J., 1997. Late Middle to Late Ordovician seismites of Kentucky, southwest Ohio and Virginia: Sedimentary recorders of earthquakes in the Appalachian Basin. *Geological Society of America Bulletin* 109: 489–503.

POTTER, P.E., 1996. Exploring the Geology of the Cincinnati/Northern Kentucky Region. *Kentucky Geological Survey, Special Publication* 22, Series XI, 115 pp.

POTTER, P.E., AUSICH, W.I., KLEE, J., KRISSEK, L.A., MASON, C. E., SCHUMACHER, G.A., WILSON, T.R. & WRIGHT, E.M., 1991. Geology of the Alexandria-Ashland Highway (Kentucky Highway 546), Maysville to Garrison. *Lexington, Kentucky Geological Survey Joint Field Conference, Geological Society of Kentucky and Ohio Geological Society*, 64pp.

PRATT, B.R. & MIALL, A. D., 1993. Anatomy of a bioclastic grainstone megashoal (Middle Silurian, southern Ontario) revealed by ground-penetrating radar. *Geology* 21: 223–226.

RAY, D.C. & BRETT, C.E., 2001. Sequence and event stratigraphy of the type Wenlock (Silurian): Midland Platform England: Comparison with eastern Laurentia. *Geological Society of America Abstracts with Programs* 33 (1): A-16.

REXROAD, C.B., 1970. An outline of Silurian conodont zones in the Illinois Basin and the Cincinnati Arch area. In *Correlation of the North American Silurian rocks*, W.B.N. Berry & A.J. Boucot, eds, *Geological Society of America Special Paper* 102, 91–94.

REXROAD, C.B. & RICKARD, L.V., 1965. Zonal conodonts from the Silurian strata of the Niagara Gorge. *Journal of Paleontology* 39: 1217–1220.

SCHNEIDER, K.A. & AUSICH, W.I., 2002. Paleoecology of framebuilders in Early Silurian reefs (Brassfield Formation, Southwestern Ohio): *Palaios* 17: 237–248.

SCOTESE, C.R., 1990. Atlas of Phanerozoic Plate Tectonic Reconstructions: International Lithophase Program (IUU-IUGS), *Paleomap Project Technical Report* 10-90-1.

SLOSS, L.L., 1963. Sequences in the cratonic interior of North America. *Geological Society of America Bulletin* 74: 93–114.

SMOSNA, R. & PATCHEN, D., 1978. Silurian evolution of the central Appalachian Basin. *American Association of Petroleum Geologists, Bulletin* 62: 2308–2328.

STOTT, C.A. & VON BITTER, P. M., 1999. Lithofacies and age variation in the Fossil Hill Formation (Lower Silurian), southern Georgian Bay region, Ontario. *Canadian Journal of Earth Sciences* 36: 1743–1762.

TELFORD, P.G., 1978. Silurian stratigraphy of the Niagara Escarpment, Niagara Falls to the Bruce Peninsula: *Geological Association of Canada, Toronto '78 Field Trips Guidebook*, p. 28–42

VAIL, P.R., MITCHUM, R.M., JR. & THOMPSON, S., III, 1977. Seismic stratigraphy and global changes of sea level, Part 4: Global cycles of relative changes in sea level. In *Seismic Stratigraphy Applications to Hydrocarbon Exploration*, C.E. Payton, ed, *American Association of Petroleum Geologists, Memoir* 26, 83–97.

VAIL, P.R., AUDEMARD, F., BOWMAN, S.A., EISNER, P.N. & PÉRÈZ-CRUZ, C., 1991. The stratigraphic signatures of tectonics, eustasy and sedimentation: An overview. In *Cycles and Events in Stratigraphy*, G. Einsele, W. Ricken & A. Seilacher, eds, Springer, New York, 617–659.

VAN WAGONER, J.C., POSAMENTIER, H.W., MITCHUM, R.M., III, VAIL, P.R., SARG, J.F., LOUTIT, T.S. & HARDENBOL, J., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. In *Sea-Level Changes: An Integrated Approach*, C.K. Wilgus, B.S. Hastings, C.G. Kendall, H.W. Posamentier, C.A. Ross & J.C. Van Wagoner, eds, *Society of Economic Paleontologists and Mineralogists, Special Publication* 42, 39–45.

WILGUS, C.K., HASTINGS, B.S., KENDALL, C.G., POSAMENTIER, H.W., ROSS, C.A. & VAN WAGONER, J.C., eds, 1988. Sea-Level Changes: An Integrated Approach. *Society of Economic Paleontologists and Mineralogists, Special Publication* 42. 407 pp.

WITZKE, B.J., LUDVIGSON, G.A. & DAY, J.E., 1996. Introduction: Paleozoic applications of sequence stratigraphy. In *Paleozoic Sequence Stratigraphy: Views from the North American Craton*, B.J. Witzke, G.A. Ludvigson & J.E. Day, eds, *Geological Society of America Special Paper*, 1–6.

HIGHLY SILICIFIED EARLY DEVONIAN (EMSIAN) BRACHIOPODS FROM THE MURRINDAL LIMESTONE, BUCHAN, EASTERN VICTORIA

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VALENTINE, J. L., 2005. Silicified Early Devonian (Emsian) brachiopods from the Murrindal Limestone, Buchan, eastern Victoria. *Proceedings of the Royal Society of Victoria* 117(2): 199–264. ISSN 0035-9211.

Silicified Early Devonian (Emsian; *perbonus* Zone) brachiopods from the Murrindal Limestone of eastern Victoria are documented in their entirety for the first time. The fauna consists of 35 species, assigned to 31 genera, and shows closest faunal similarities with the brachiopod faunas of the Murrumbidgee Group of the Taemas-Wee Jasper area of New South Wales. The Murrindal Limestone brachiopod fauna is dominated taxonomically by strophomenids (five genera and five species), orthids (eight genera and eight species) and spiriferids (five genera and six species). However, the atrypids, especially *Atryparia penelopeae* (Chatterton, 1973) (784 ventral valves; 794 dorsal valves; 778 articulated specimens), dominate the fauna numerically. New taxa include the dalmanellid subfamily Bidigitinae subfam. nov. with type species *Bidigitus murrindalensis* gen. et sp. nov.; other new taxa are a dalmanellid, *Biernatium catastum* sp. nov., and a leptaenid, *Notoleptaena adamantea* sp. nov.

Keywords: Buchan, Early Devonian, Murrindal Limestone, rhynchonelliformean brachiopods, Victoria

HIGHLY diverse brachiopod faunas occur in many eastern Australian Devonian carbonate sequences. These include the Broken River Group and Ukalunda Beds of northeast Queensland (Brock 1989; Brock & Talent, 1993); the Garra Limestone (Savage 1969; Lenz & Johnson 1985a, b; Farrell 1992; Brock 2003a, b) and the Murrumbidgee Group (Chatterton 1973) of New South Wales; and the Buchan Group of eastern Victoria (Talent 1956a). However, despite having such prominence, many brachiopod faunas remain undocumented.

The Buchan Group of eastern Victoria (Fig. 1) contains some of the richest Devonian brachiopod faunas in eastern Australia. Despite being known since the 1860s (Selwyn & Ulrich 1867; McCoy 1867), only the brachiopods of the Buchan Caves Limestone have been fully documented (Talent 1956a). Very few taxa have been documented from the Taravale Formation and Murrindal Limestone (Chapman 1913; Gill 1951; Campbell & Talent 1967; Teichert & Talent 1958; Talent et al. 2000, 2001).

GEOLOGY AND STRATIGRAPHY

The Buchan Group, a 1100 m carbonate-mudstone succession, outcrops in a broad north-south synclinal structure in the Buchan-Murrindal area of eastern Victoria (Fig. 1) as well as at Bindi, The Basin and numerous other areas where only parts of the lowest unit, the Buchan Caves Limestone have been preserved (see Mawson 1987: figs 1–5). The Buchan Caves Limestone rests disconformably, or with minor unconformity, on the Snowy River Volcanics (Fig. 2) (Teichert & Talent 1958; Mawson 1987; Mawson et al. 1992) and is conformably overlain by the Taravale Formation (Fig. 2), a sequence of mudstones and shales with subordinate limestones tending to be nodular (Teichert & Talent 1958; Mawson 1987) and apparently deposited on a southwards sloping submarine shelf (Talent 1965a, 1969). The group reaches a thickness of around 600 m at the southern end of the Buchan Syncline. At the northern end of the Buchan Syncline, the Taravale Formation occurs as two poorly outcropping tongues of mudstone and calcareous mudstone with occasional beds of limestone and nodular limestone: the Pyramids Mudstone Member (Teichert & Talent 1958) — between the Buchan Caves Limestone and the overlying Murrindal Limestone (Fig. 2) — and an unnamed poorly outcropping tongue, referred to as the Upper Taravale Formation in Fig. 2, overlying the Murrindal Limestone and known primarily from deeply weathered exposures in road cuttings; the stratigraphy and palaeontology of this unnamed member are poorly known. The Pyramids Member

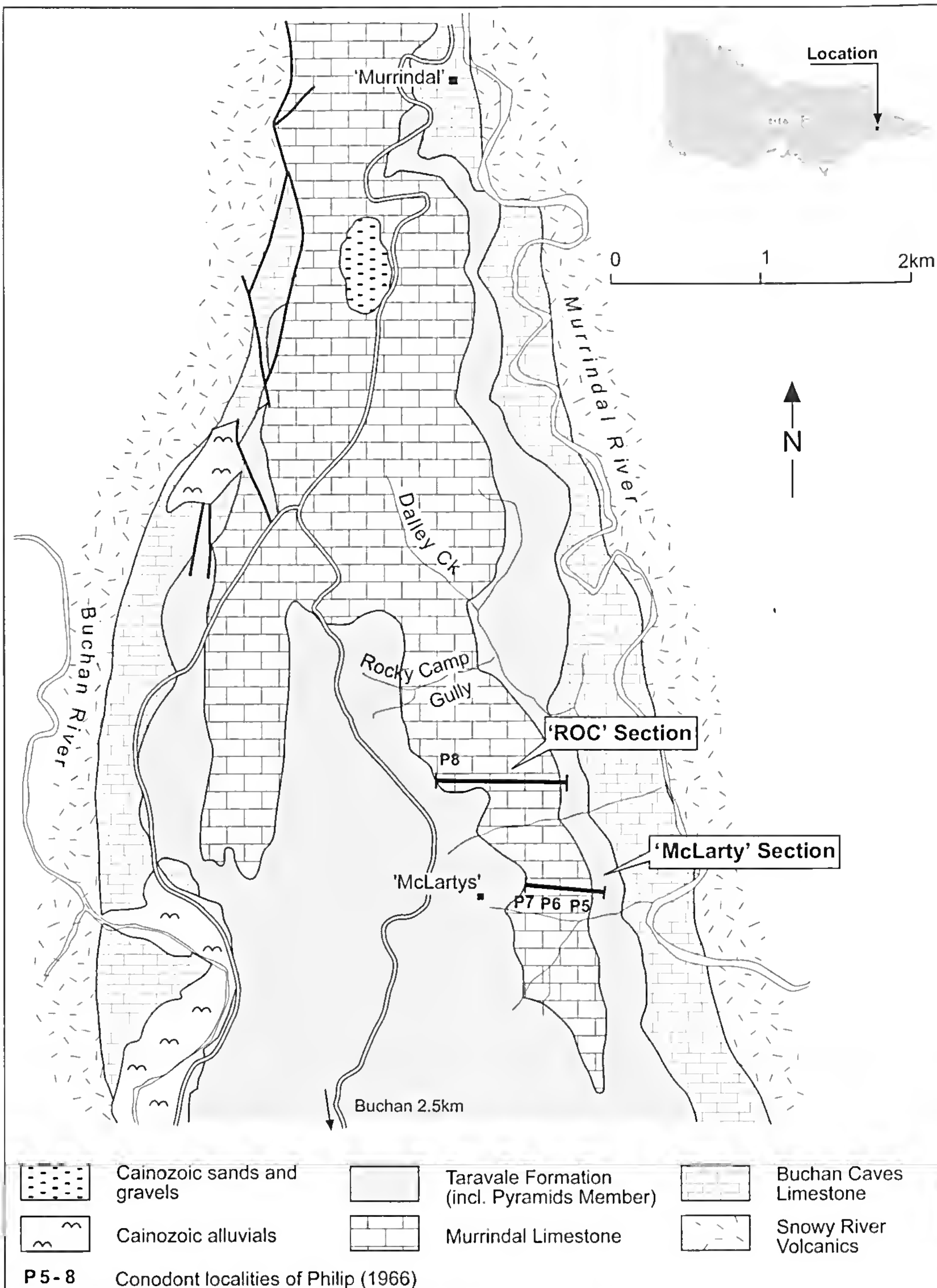


Fig. 1. The Buchan-Murrindal area, eastern Victoria (after Mawson 1987)

is occasionally highly fossiliferous, the proportion of carbonate increasing northwards until a short distance north of Murrindal State School (see Mawson 1987: fig. 1) where it can no longer be differentiated from the overlying and underlying units (Teichert & Talent 1958; Mawson 1987).

The middle part of the Taravale Formation grades laterally into the Murrindal Limestone a few kilometres north of Buchan (Fig. 2). This unit is up to 250 m thick and consists of a broad spectrum of carbonate lithologies including micrites, calcarenites, a few rudites, calcareous mudstones (especially southwards towards Moon's Road), algal mudstones and a prominent algal biostrome outcropping about 75 m above the base of the formation. Based on conodont data, it has been suggested that the Murrindal Limestone accumulated more rapidly than the deeper water nodular limestones, shales and impure limestones of the Taravale Formation (Hyland & Pyemont in Mawson et al. 1988). The wide range of carbonate lithologies accords with a situation in which there was considerable patchiness in carbonate environments (and biofacies), the areas and relationships of these fluctuating through time.

Teichert & Talent (1958) discriminated two members within the Murrindal Limestone (Fig. 2), the well-bedded, typically dark grey, McLarty Member representing shallow shelf, but not intertidal carbonate environments, and the less well-bedded, paler grey limestones of the Rocky Camp Member, interpreted as being biohermal in origin (Mawson 1987; Wallace 1987; Holloway 1996). These buildups are now interpreted as carbonate mud-mounds (Wallace 1987).

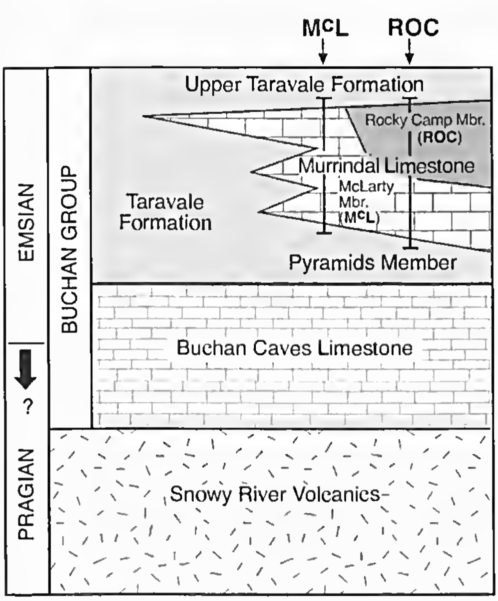


Fig. 2. Stratigraphy of the Buchan district showing the two sections, McL and ROC, through the Murrindal Limestone sampled for brachiopods (not to scale) (after Mawson 1987 and Holloway 1996).

PREVIOUS WORK

The presence of limestone outcrops in the Buchan-Murrindal area of eastern Victoria was first mentioned by Selwyn & Ulrich (1867) who believed they may have been Devonian in age, based on McCoy's (1867) identification of *Spirifera laevicosta* (Valenciennes in Lamarck, 1819) (species name misspelled *laevicostata* until Chapman's (1905) review of the species), a Middle Devonian brachiopod occurring in the Eifel Hills of western Germany. McCoy (1876) described in detail the first fossils from the Buchan limestones which included *Favosites goldfussi* d'Orbigny, 1850, *Spirifera laevicosta*, *Chonetes australis* McCoy, 1876, *Phragmoceras subtrigonum* McCoy, 1876, and *Asterolepis ornatus* var. *australis* McCoy, 1876. The first geological survey of the area was undertaken by Howitt (1876: 203), who described the Buchan limestones as being compact and dark blue to almost black limestone deposited some distance from land in seas of moderate depth. Howitt (1876) accepted McCoy's (1867) view that the Buchan limestones were Middle Devonian, an assessment not seriously challenged until the 1960s.

During the 1940s, Teichert undertook the first detailed study of the geological structure and stratigraphy of the Buchan-Murrindal area and is primarily responsible for the stratigraphic nomenclature that came to be applied to what was formerly referred to as the 'Buchan Limestones'. The lowest unit he termed the Cave Limestone (Teichert 1948), subsequently amended to Buchan Caves Limestone to avoid confusion with similarly named units elsewhere in Australia. He initially regarded the overlying limestone-mudstone sequence as consisting of two units, the Lower Murrindal Beds — with the goniatite *Gyroceratites* von Meyer, 1831 and bactritid *Lobobactrites* Schindewolf, 1932 — and the Upper Murrindal Beds. This nomenclature was used by Hill (1950) when describing corals collected by Teichert and sent to her for identification.

Teichert & Talent (1958) provided a comprehensive account of the geology and stratigraphy of the post-Snowy River Volcanics sequence of the Buchan area and, on the basis of extensive collections, provided the first overview of the abundant and diverse fossil assemblages occurring at many horizons throughout the Buchan Group. Since then, several groups have received additional attention: fish remains (Long 1984, 1986; Burrow & Turner 1998; Basden 1999), conodonts (Mawson 1987; Hyland & Pyemont in Mawson et al. 1988; Pyemont 1990; Mawson et al. 1992), chitinozoans (Winchester-Seeto & Paris 1989; Winchester-Seeto 1996), bivalves (Johnston 1993), stromatoporoids (Webby et al. 1993), trilobites (Holloway 1996), foraminifers (Bell 1996; Bell & Winchester-Seeto 1999), dacryoconarids (Alberti 1993, 1995) and disarticulated crinoid remains (Stukalina & Talent unpubl. data).

Teichert & Talent (1958) believed the Buchan Group to be early Middle Devonian in age, with the possibility that the Buchan Caves Limestone extended down into the latest part of the Early Devonian. This assessment was based primarily on the presence of the bactritid, *Lobobactrites* and goniatite, *Gyroceratites* (Teichert 1948) from the Taravale Formation, and to a lesser extent on the presence of the trilobites *Harpes* Goldfuss, 1839 and *Scutellum* Pusch, 1833 in the uppermost parts of the Buchan Group. Hill's (1950) opinion, based on tabulate and rugose corals, was in accord with this assignment.

Erben (1960, 1962, 1964, 1965), Chlupáč (1976) and House (1979) reconsidered the identity of the goniatites described by Teichert (1948) and, *inter alia*, proposed several new genera including two from Buchan, *Teicherticeras* Erben, 1960 (an Emsian form) and, subsequently, *Talenticeras* Erben, 1965. This, together with subsequent work on other groups including conodonts (Philip & Pedder 1964; Philip 1966), triggered realization that some, if not all, of the sequence was late Early Devonian (Emsian) in age.

The pioneering conodont work of Philip & Pedder (1964) and Philip (1966) has now been superseded by conodonts from several hundred samples collected from measured stratigraphic sections (often bed-by-bed sampling; present database > 10,000 conodonts, Mawson pers. comm.) through all units of the Buchan Group in the Buchan-Murrindal area and from Bindi, The Basin, Dead Horse Creek, and Boulder Flat, as well as spot sampling in several other areas (Mawson 1987; Mawson et al. 1988, 1992; Pyemont 1990). This work not only provided tightly constrained ages for all units of the Buchan Group, but conodont data through the goniatite-bearing intervals low in the Taravale Formation suggest these may be the oldest ammonoids in the world (Mawson 1987). Conodont studies of Mawson (1987) and Mawson et al. (1988, 1992) indicated that: the Buchan Caves Limestone belongs to the *dehiscens* Zone (but not latest *dehiscens* Zone), possibly extending down into the *pireneae* Zone (uppermost zone of the Pragian); the Taravale Formation spans the interval from late *dehiscens* Zone through to somewhere in the *serotinus* Zone (late Emsian); the Pyramids Mudstone Member of the Taravale Formation is late *dehiscens* Zone to early *perbonus* Zone; and the Murrindal Limestone extends from early, but not earliest, *perbonus* Zone, through to just before the base of the *inversus* Zone (Mawson et al. 1988: 498–499, table 8).

Bed-by-bed sampling for conodonts along McLarty's Ridge (Fig. 1) undertaken by Mawson, Talent and Hyland embraced the uppermost 62 m of the Pyramids Member of the Taravale Formation, 158 m of the Murrindal Limestone and finished low in the upper, unnamed tongue of Taravale Formation (Fig. 4). Of the 3388 conodonts recovered, *Polygnathus perbonus* (Philip, 1966) and *P. nothoperbonus* Mawson, 1987, were present from the first to the last beds sampled, indicating that the entire section lies within the *perbonus* Zone. A similar exercise conducted along Rocky Camp Ridge (Fig. 1) provided materials for Pyemont's (1990) dissertation. This section commenced 17 m below the base of the Murrindal Limestone and passed through 147.5 m of the Murrindal Limestone and ended very low in the upper tongue of Taravale Formation (Fig. 3). It yielded 1922 conodonts of which *P. perbonus* and *P. nothoperbonus* were dominant; this section too lay entirely within the *perbonus* Zone.

No chitinozoans were obtained from the Murrindal Limestone, but the Taravale Formation — more pelagic as indicated by goniatite and dacryoconarid faunas — produced 55 species of chitinozoans grouped in seven assemblages (Winchester-Seeto & Paris 1989; Winchester-Seeto 1996), that appear to have only local stratigraphic application. Fifteen of the reported species are new and a further 15 are probably new. Only five species have tentative relationships with Emsian species from Europe (see Winchester-Seeto 1996: 159–160).

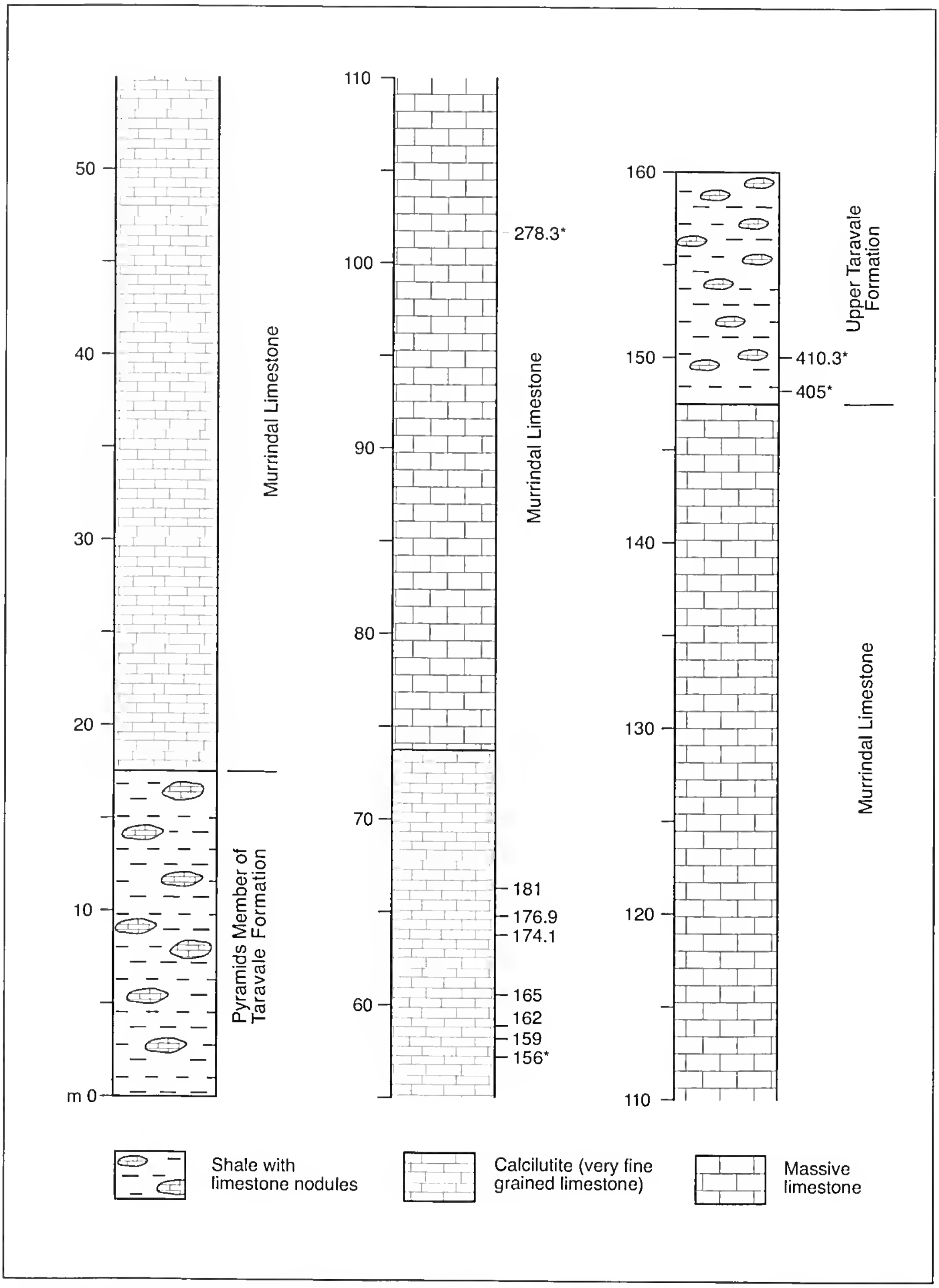


Fig. 3. ROC stratigraphic section (*perbonus Zone*). Numbers on the right hand side of columns indicate silicified horizons from which brachiopods were collected. Those with an asterisk indicate non-silicified horizons.

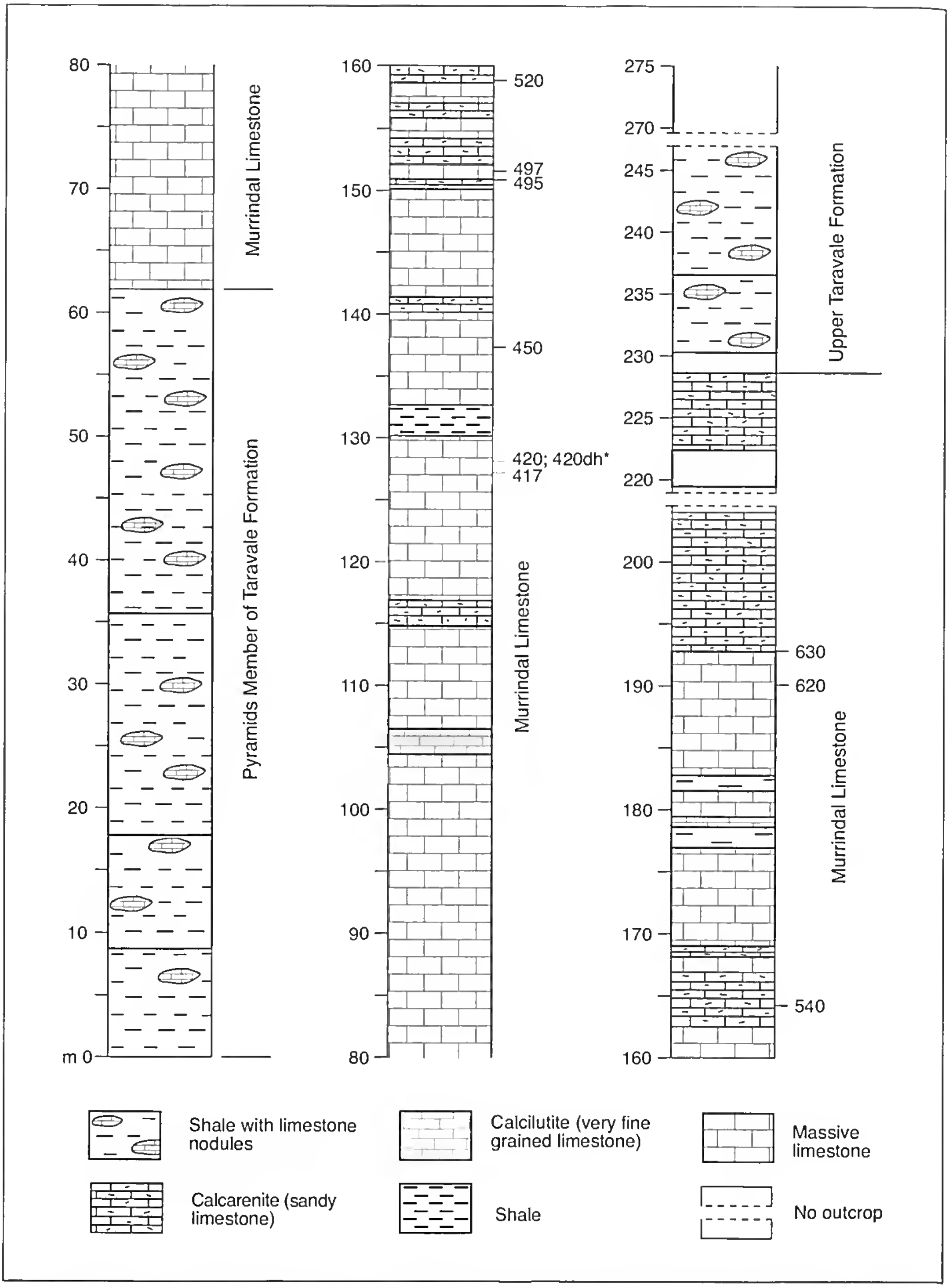


Fig. 4. McL stratigraphic section (*perbonus Zone*) (after Hyland & Pyemont in Mawson et al. 1988). Numbers on the right hand side of columns indicate silicified horizons from which brachiopods were collected. (*dh = down hill).

Horizons / Brachiopod taxa	ROC 156			ROC 159			ROC 162			ROC 165			ROC 174.1			ROC 176.9			ROC 179			ROC 181			ROC 278.3			ROC 405			ROC 410.3		
	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a
Opsiconidion arcticon	1																									1			1				
Opsiconidion sp. cf. *O. aldridgei*																																2	
Craniops australis				2	3											3	4	1															
Notoleptaena adamantea sp. nov.				11	2	3	34	17	5	4		7	3	1		6	1	2				16	9										
Cymostrophia (*Protocymostrophia*) *dickinsi*				9	2	1	5			7	5	5	1			3	2	2															
Maluroostrophia sp. cf. *M. flabellicauda*				2		1									1	1		1															
Nadiastrophia patmorei				19		3	4		1						1	4		1				3											
Mesoleptostrophia (*Paraleptostrophia*) *clarkei*				6	4	5	9						1			2	1					5											
Johnsonetes australis							1		3	15		7	1								3												
Johnsonetes ? sp. cf. *J. culleni*											1																						
Eoschuchertella murphyi											3			1																			
Dolerorthis sp.				1			4	1	3																								
Hesperorthidae gen. et sp. indet.														1																			
Tyersella spedeni				88	82	1	71	51	6				35	42	5	8	17	1				15	21	5									
Prokopia hillae						1				5				1																			
Resserella careyi				150	79	46	218	139	87	25	9	17	79	47	4	19	9	2	1		12	28	11										
Bidigitus murrindalensis gen. et sp. nov.				5	4		40	17			3	1	9	2		2	2					13	4										
Aulacella philipi				4	3	1		3			1	5	73									1											
Euglossinotoechia linki									1			6			2			3															
'*Pugnax*' *oepiki*				2		37			9	4		10						28	1		9			10									
Spinella buchanensis buchanensis				2	6		3																										
Spinella yassensis				1			4					1	2						2														
Howellella (*Howellella*) *textilis*						1			1	5	2	6																					
Howittia howitti				2	1	1	2	3																									
Cyrtina wellingtonensis						1	1		21	19	9	32						1			1			2									
Atryparia penelopeae				28	18	57	506	520	458	25	21	91	7	1	1	25	27	12	1		4	82	83	42									
Variatrypa (*Variatrypa*) *erectirostris*					1		41	18	72	3	2	19				5	5	1	3		6	8	4	1									
Buchanathyris westoni				20	28	6	105	109	9	10	3	6		3		15	18		6	5	11	9	25										
Micidus shandkyddi									5			3									2												
Micidus ? *glaber*									1				2																				

Table 1. Stratigraphic distribution of brachiopods collected from the ROC section (*perbonus* Zone) through the Murrindal Limestone, Buchan, Victoria. Abbreviations: vv = ventral valve; dv = dorsal valve; a = articulated specimen.

Horizons / Brachiopod taxa	M^cL 417			M^cL 420			M^cL 420dh			M^cL 450			M^cL 495			M^cL 497			M^cL 520			M^cL 540			M^cL 620		
	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a	vv	dv	a
Craniops australis	5	2	1																1								
Notoleptaena adamantea sp. nov.	3	1											1														
Cymostrophia (*Protocymostrophia*) *dickinsi*	2		1				12	7	1										6	2	3						
Malurostrophia sp. cf. *M. flabellicauda*																			1								
Nadiastrophia patmorei							1				1																
Mesoleptostrophia (*Paraleptostrophia*) *clarkei*	3				1			3					1						2								
Johnsonetes australis			2				4												2								
Eoschuchertella murphyi		1				1													1								
Dolerorthis sp.	7	1	2																								
Tyersella spedeni	19	23	4	5	7			17																			
Prokopia hillae		1	1				63	21	11								1		3	9							
Resserella careyi	60	24	10	4	4	1	16	23	6										4	1							
Bidigitus murrindalensis gen. et sp. nov.	7	4	1				7	1	1																		
Biernatium catastum sp. nov.																			13	20	1						
Aulacella philipi	5	10	1	27	40		4	7											9	24	2				1		
Eoglossinotoechia linki			2															1									
'*Pugnax*' *oepiki*	4	2	137			2												3									
Spinella buchanensis buchanensis	5	3		2																							
Spinella yassensis	2																										
Ambocoelia sp. aff. *A. runnegari*	3	3														2	1	3	11	9	1						
Delthyris ? sp.							4				3																
Howellella (*Howellella*) *textilis*	31	19	4	5	2	3	5	4	6							2	1		16	10	1						
Howittia howitti		3																									
Cyrtina wellingtonensis	12	4	16	2		1	49	38	83										17	20	1						
Atryparia penelopeae	105	115	109	1							1			3		2	2	1	2	3	1			2			
Variatrypa (*Variatrypa*) *erectirostris*	8	1	8										3														
Coelospira dayi															1	5		12									
Buchanathyris westoni	41	36	1	3	2		1	3											1	2							
Nucleospira sp.													2														
Micidus shandkyddi		1	11		1	1																					
Micidus ? *glaber*			11			1												17									

Table 2. Stratigraphic distribution of brachiopods collected from the McL section (*perbonus* Zone) through the Murrindal Limestone, Buchan, Victoria. Abbreviations as for Table 1.

SYSTEMATIC PALEONTOLOGY

Brachiopods for this project were collected from silicified horizons along the Rocky Camp Ridge (ROC) and McLarty Ridge (McL) sections through the Murrindal Limestone (Figs 1, 3, 4, Tables 1, 2). All type and figured material is lodged in the palaeontological collections of the Australian Museum (AM F).

Phylum BRACHIOPODA Duméril, 1806

Remarks. Unless otherwise mentioned, the higher level classification used herein follows that of Kaesler (2000, 2002).

Subphylum LINGULIFORMEA Williams, Carlson, Brunton, Holmer & Popov, 1996
Class LINGULATA Gorjansky & Popov, 1985
Order ACROTRETIDA Kuhn, 1989
Superfamily ACROTRETOIDEA Schuchert, 1893
Family BIERNATIDAE Holmer, 1989

Opsiconidion Ludvigsen, 1974

Type species. By original designation of Ludvigsen (1974: 143); *Opsiconidion arcticon* Ludvigsen, 1974; early Emsian of the Michelle Formation, Yukon Territory, Canada.

Remarks. Opsiconidion is one of only six known genera of post-Ordovician acrotretid brachiopods (Krause & Rowell 1975; Biernat & Bednarczyk 1990; Brock et al. 1995; Mergl 2001) and ranges from Ordovician (Ashgill) to Middle or ?Upper Devonian (Holmer & Popov 2000). Brock et al. (1995) documented four species of *Opsiconidion* from New South Wales and Victoria ranging from the Lochkovian (*pesavis* Zone) to Emsian (*dehiscens* Zone). Brock et al. (1995) also reported the presence of three poorly preserved dorsal valves from the Middle Devonian Yarramie Formation of New South Wales. These were questionably referred to *O. minor* Popov, 1981a, possibly extending the stratigraphic range of this genus in Australia to the Givetian (*varcus* Zone). However, additional material is required to confirm this.

Opsiconidion arcticon Ludvigsen, 1974
Fig. 5A-C

Opsiconidion arcticon Ludvigsen 1974: 145, fig. 4, 1–3; fig. 5, 1–8.-von Bitter & Ludvigsen 1979: 707, pl. 90, figs 1–12; pl. 91, figs 1–12.-Brock, Engelbretsen & Dean-Jones 1995: 111, figs 4A-F.-Brock 2003a: 104, pl. 1, figs 8–13, 15–16.

Material. Figured material: AM F117236 (Fig. 5A, B): ventral valve from sample ROC 156; AM F117237 (Fig. 5C): dorsal valve from sample ROC 156. Unfigured material: one dorsal valve.

Description. See Ludvigsen (1974: 145) and von Bitter & Ludvigsen (1979: 707).

Remarks. Opsiconidion arcticon was first documented in Australia by Brock et al. (1995: 111) from various Early Devonian localities in New South Wales and Victoria. The presence of *O. arcticon* in the ROC section of the Murrindal Limestone extends its stratigraphic range in Australia from the Pragian (*kindlei* Zone) into the Emsian (*perbonus* Zone). *Opsiconidion arcticon* has otherwise been recovered from the Lochkovian Garra Limestone at Eurimbla (Brock 2003a), the Emsian Michelle Formation in the Yukon Territory of Canada (Ludvigsen 1974) and the Lower and Middle Devonian Bois Blanc, Onondaga and Dundee Formations of Ontario (von Bitter & Ludvigsen 1979).

As outlined by Brock et al. (1995) and Brock (2003a), the diagnostic features of *Opsiconidion* are the morphology of the dorsal valve pseudointerarea and to a lesser extent, the outline of the dorsal valve. The dorsal valve pseudointerarea of *O. arcticon* is crescentic and lacks a median plate, whereas the dorsal valve outline is almost circular (Fig. 5C). *Opsiconidion* sp. cf. *O. aldridgei* (Cocks, 1979), from various Early Devonian localities in New South Wales and Victoria (see Brock et al. 1995: 111 and Brock 2003a: 104), has a less well rounded dorsal valve and a dorsal valve pseudointerarea with a straight anterior margin and a well defined median plate. *Opsiconidion minor* from the Emsian of Valnov Island, Novaja Zemlja (Popov 1981a) and various localities in New South Wales and Victoria (see Brock et al. 1995: 113), differs in having an acutely subtriangular dorsal valve pseudointerarea, a well-defined median plate and propareas and a less well-rounded dorsal valve. *Opsiconidion robustum* Brock, Engelbretsen & Dean-Jones, 1995 from the Early Devonian of New South Wales (see Brock et al. 1995: 114) is distinguished by its external ornament of well defined concentric fila, squat, conical and robust ventral valve, straight dorsal valve pseudointerarea and sub-polygonal dorsal valve outline.

Opsiconidion sp. cf. **O. aldridgei** (Cocks, 1979)
Fig. 5D, E

?*Caenotreta aldridgei* sp. nov. Cocks 1979: 96, pl. 13, figs 1–7; pl. 14, figs 1–4.
?*Caenotreta celloni* sp. nov. Cocks 1979: 98, pl. 14, figs 6–8.
Opsiconidion sp. cf. *O. aldridgei*-Brock, Engelbretsen & Dean-Jones 1995: 111, fig. 5A-K.-Brock 2003a: 104, pl. 1, fig. 14.

Material. Figured material: AM F117238 (Fig. 5D): dorsal valve from ROC 410.3; AM F117239 (Fig. 5E): dorsal valve from ROC 410.3.

Description. See Cocks (1979: 96).

Remarks. The dorsal valve pseudointerarea of *O. aldridgei* is short and wide, with a straight anterior edge and a well-defined median plate. The dorsal valve is subcircular in outline (Cocks 1979; Brock et al. 1995). Brock et al. (1995) and Brock (2003a) differentiated between *O.* sp. cf. *O. aldridgei* from various Early Devonian localities in New South Wales and Victoria (see Brock et al. 1995: 111 and Brock 2003a: 104) and *O. aldridgei* from the Llandovery of the Welsh Borderlands (Cocks 1979), the Llandovery to Wenlock of Saaremaa, Estonia (Popov 1981b) and the Boree Creek Formation of central-western New South Wales (Valentine et al. 2003), because the median plate of the Early Devonian specimens is less distinct. The Murrindal specimens are most similar to those described by Brock et al. (1995) and Brock (2003a). This extends the stratigraphic range of the O. sp. cf. *O. aldridgei* from the Pragian (*kindlei* Zone) to the Emsian (*perbonus* Zone).

Opsiconidion praecursor Popov, Nölvak & Holmer, 1994, from the Upper Ordovician Harju Series of southern Estonia, is very similar to *O. aldridgei.* The dorsal valve outline of both species is subcircular and both have an anacline pseudointerarea with a straight anterior margin. *Opsiconidion praecursor* differs in being smaller, having a relatively smaller dorsal valve pseudointerarea and possessing large larval pits surrounded by clusters of smaller ones (Popov et al. 1994).

Opsiconidion arcticon, from various Early Devonian localities in New South Wales and Victoria (see Brock et al. 1995: 111 and Brock 2003a: 104), the Emsian Michelle Formation in the Yukon Territory of Canada (Ludvigsen 1974), and the Lower and Middle Devonian Bois Blanc, Onondaga and Dundee Formations of Ontario (von Bitter & Ludvigsen 1979), possesses a similar ventral valve to *O.* sp. cf. *O. aldridgei*, but the latter has a slightly flattened pseudointerarea. The dorsal valve of *O. arcticon* has a more circular outline and crescentic pseudointerarea. *Opsiconidion minor*, from the Emsian of Valnov Island, Novaja Zemlja (Popov 1981a) and also recovered by Brock et al. (1995: 113) from various Early Devonian localities in New South Wales and Victoria, differs in having an acutely subtriangular pseudointerarea and a well-defined median plate. *Opsiconidion robustum* from the Early Devonian of New South Wales and Victoria (Brock et al. 1995: 114) is distinguishable by its external ornament of well-defined concentric fila, its squat, conical and robust ventral valve and sub-polygonal dorsal valve outline.

Subphylum CRANIIFORMEA Popov, Bassett, Holmer & Laurie, 1993
Class CRANIATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order CRANIOPSIDA Gorjansky & Popov, 1985
Superfamily CRANIOPSOIDEA Williams, 1963
Family CRANIOPSIDAE Williams, 1963

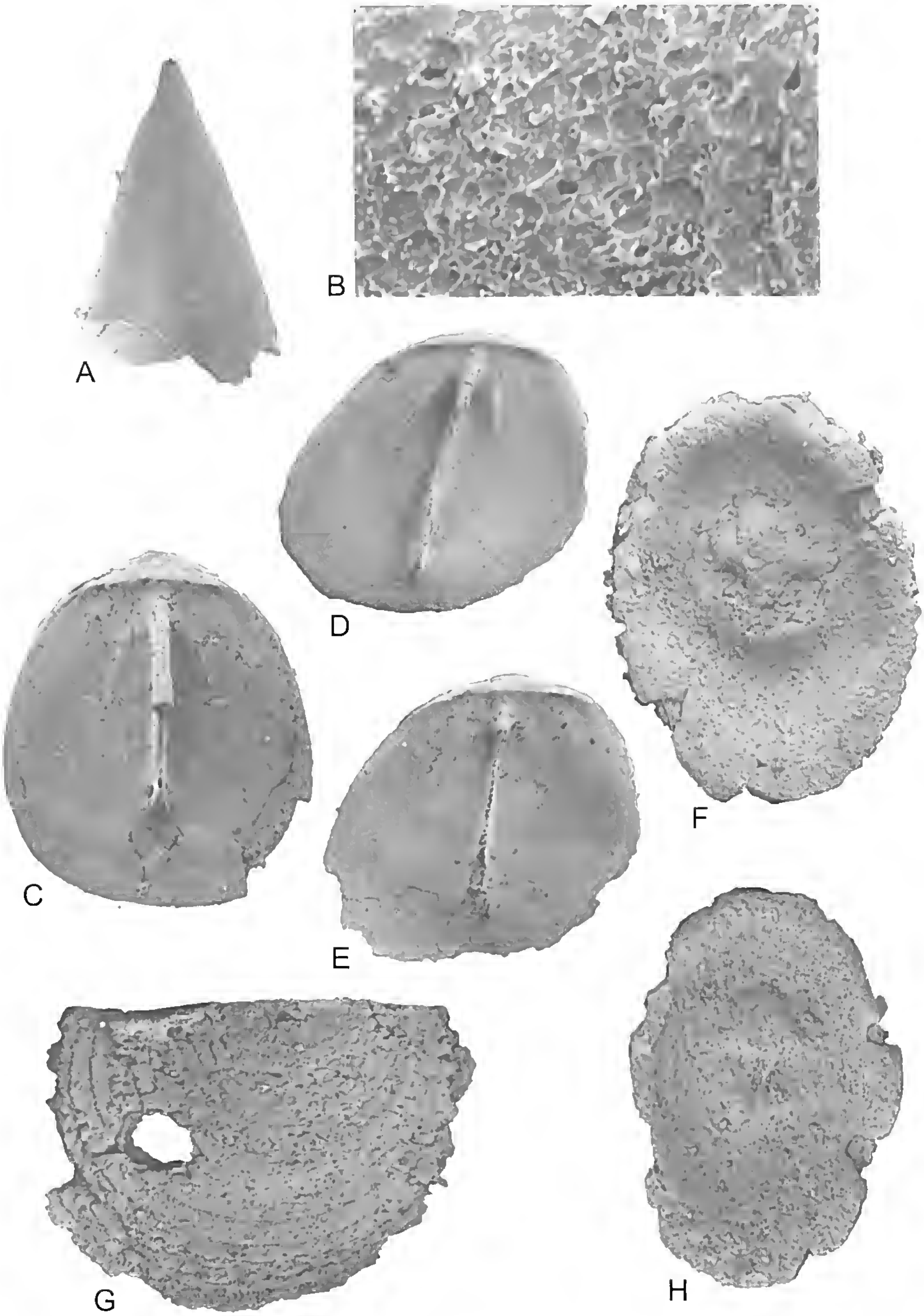
Craniops Hall, 1859a

Type species. By original designation of Hall (1859a: 84); *Orbicula? squamiformis* Hall, 1843; Lochkovian of the Helderberg Group, New York, America.

Craniops australis Chatterton, 1973
Fig. 5F-H

Craniops australis sp. nov. Chatterton 1973: 17, pl. 1, figs 1–7; pl. 5, figs 26–30.

Fig. 5. A-C, *Opsiconidion arcticon* Ludvigsen, 1974. A, B, ventral valve lateral view, x 120, close up of ventral valve larval shell pitting x 2670, ROC 156, AM F117236. C, dorsal valve interior, ROC 156, AM F117237, x 94. D, E, *Opsiconidion* sp. cf. *O. aldridgei* (Cocks, 1979). D, dorsal valve interior in lateral oblique view, ROC 410.3, AM F117238, x 69. E, dorsal valve interior in lateral oblique view, ROC 410.3, AM F117239, x 69. F-H, *Craniops australis* Chatterton, 1973. F, ventral valve interior, ROC 176.9, AM F117240, x 37. G, ventral valve exterior, ROC 176.9, AM F117241, x 33. H, dorsal valve interior, ROC 159, AM F117242, x 37.


A
B
C
D
E
F
G
H

Material. Figured material: AM F117240 (Fig. 5F): ventral valve from ROC 176.9; AM F117241 (Fig. 5G): ventral valve from ROC 176.9; AM F117242 (Fig. 5H) dorsal valve from ROC 159. Unfigured material: ten ventral valves, seven dorsal valves and two complete specimens.

Description. See Chatterton (1973: 17).

Remarks. Craniops australis from the Emsian '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas and the Murrindal Limestone at Buchan, differs in several ways from the *C. squamiformis. Craniops squamiformis* has a thinner shell, a more subquadrate outline and finer, more numerous and closely spaced growth lines. The apex of *C. australis* is located closer to the posterior margin than the apex of *C. squamiformis*. Hall (1859a) also mentioned the presence of fine radiating striae crossing the lamellae in well-preserved specimens of *C. squamiformis*, as does Chatterton (1973) for some specimens of *C. australis*. However, Chatterton's (1973: pl. 1, figs 1–7; pl. 5, figs 26–30) figured material show no trace of radial striae, nor do any of the Murrindal specimens (Fig. 5G).

Craniops australis is the only definite occurrence of this genus in Australia. A questionable occurrence was reported by Strusz (1982) from the Wenlock Walker Volcanics near Canberra. Though externally resembling *Craniops*, this assignment is tentative owing to a lack of material showing sufficient detail of internal features and doubts over the presence of an attachment scar (Strusz 1982).

Craniops australis appears most closely related to *Craniops* sp. 1 of Perry (1984) from the late Emsian of the Delorme Formation of western Canada. Although both are similar in terms of outline, ornament and muscle scar impressions, the Delorme specimens possess a much more prominent attachment scar. *Craniops patina* (Hall & Clarke, 1893) from late Emsian beds of the Bois Blanc Formation of Ontario is externally similar to *C. australis*; the two species also possess similar muscle scar impressions. They differ most notably in that the dorsal valve of *C. patina* possesses a median ridge located between the anterior adductor scars.

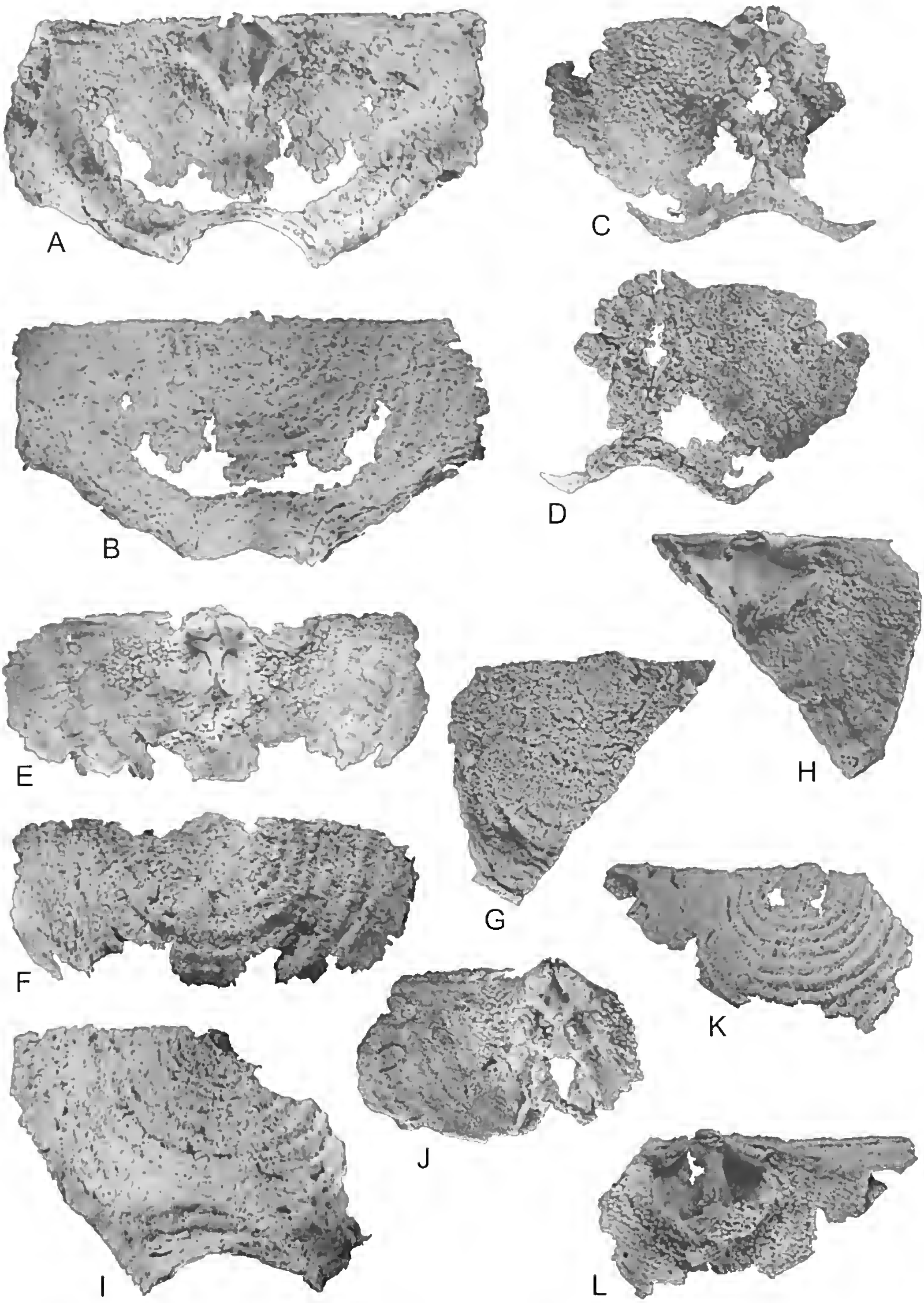
Subphylum RHYNCHONELLIFORMEA Williams, Carlson, Brunton, Holmer & Popov, 1996
Class STROPHOMENATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order STROPHOMENIDA Öpik, 1934
Superfamily STROPHOMENOIDEA King, 1846
Family RAFINESQUINIDAE Schuchert, 1913
Subfamily LEPTAENINAE Hall & Clarke, 1894

Notoleptaena Gill, 1951

Type species. By original designation of Gill (1951: 191); *Notoleptaena linguifera* Gill, 1951; Lochkovian-Pragian, Stoddart Member of the Mount Ida Formation, Heathcote-Redcastle district, Victoria, Australia.

Remarks. Apart from one species left under open nomenclature by Pajchlowa (1957) from the Devonian deposits of the eastern part of the Bodzentyn synclinal outcrops in the region of Grzegorzowice and Skaly, Poland, all occurrences of *Notoleptaena* are restricted to Australia. However, as Pajchlowa (1957) neither figured nor described this specimen, no comparisons are possible. The type species has been recovered from the Lochkovian-Pragian of the Stoddart Member of the Mount Ida Formation (Mawson & Talent 2000), and *N.* cf. *linguifera* occurs in the Pragian Garra Limestone at Wellington (Lenz & Johnson 1985a), but has since been referred to *Glossoleptaena* Havlíček, 1956 by Brock (2003a). *Notoleptaena otophera* Gill, 1951 is widely distributed, having being recovered from the Lochkovian-Pragian Mount Ida Formation unit 3 (*Pleurodictyum* Beds), the Lochkovian Humevale Formation and the latest Lochkovian Boola Siltstone of Victoria. *Notoleptaena* aff. *otophera* occurs in the ?early Lochkovian Maradana Shale of New South Wales (Savage 1974). A third species, *N. undulifera* Talent, 1956b occurs in the Pragian Tabberabbera Formation of Victoria. *Notoleptaena adamantea* extends the stratigraphic range of this genus into the Emsian (*perbonus* Zone).

Fig. 6. A-L *Notoleptaena adamantea* sp. nov. All specimens x 2. A, B, holotype, ventral valve interior and exterior, ROC 181, AM F117243. C, D, dorsal valve interior and exterior, ROC 159, AM F117244. E, F, dorsal valve interior and exterior, ROC 181, AM F117245. G, H, ventral valve exterior and interior, ROC 159, AM F117246. I, dorsal view of articulated specimen, ROC 181, AM F117247. J, dorsal valve interior, ROC 165, AM F117248. K, L, ventral valve exterior and interior, ROC 165, AM F117249.


A
B
C
D
E
F
G
H
I
J
K
L

Notoleptaena adamantea sp. nov.
Fig. 6A-L

Etymology. L., *adamantea*, like a diamond; in reference to the diamond shaped muscle field of the ventral valve.

Diagnosis. *Notoleptaena* with diamond-shaped ventral valve muscle field, surrounded by strong muscle bounding ridges. Hinge line faintly denticulate for most of length. Delthyrium trapezoidal.

Type material. Holotype: AM F117243 (Fig. 6A, B): ventral valve from ROC 181. Figured paratypes: AM F117244 (Fig. 6C, D): dorsal valve from ROC 159; AM F117245 (Fig. 6E, F): dorsal valve from ROC 181; AM F117246 (Fig. 6G, H): ventral valve from ROC 159; AM F117247 (Fig. 6I): articulated specimen from ROC 181; AM F 117248 (Fig. 6J): dorsal valve from ROC 165; AM F117249 (Fig. 6K, L): ventral valve from ROC 165. Unfigured paratypes: 75 ventral valves, 28 dorsal valves and 17 articulated specimens.

Type locality and horizon. ROC section (sample ROC 181), Emsian (*perbonus Zone*) Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Description. Semicircular outline, maximum width at, or slightly forward of, hinge line. Up to twice as wide as long. Cardinal extremities variably alate. Visceral region of ventral valve convex; medial region slightly concave. Raised lateral margins, increasing in height anteriorly until reaching strongly dorsally deflected tongue. Visceral and medial regions of dorsal valve planoconvex, valve margins concave. Ornament consisting of weakly to strongly developed and irregularly spaced concentric rugae, 0.7 mm up to 2.8 mm (averaging 1.1 mm) apart. No micro-ornament observed.

Ventral valve interarea steeply apsacline. Delthyrium trapezoidally shaped. Pseudodeltidium absent. Dorsal valve interarea small, anacline and triangular. Notothyrium narrowly triangular, with small, fragile chilidium.

Ventral valve interior with well developed, elongately oval and crenulate teeth lying subparallel to hinge line. A broad median ridge begins one quarter to halfway across muscle field, rapidly increasing in height, and slightly in width, anteriorly. Muscle field diamond shaped and strongly excavated. Diductor scars triangular and separated by median ridge. Adductor scars long, narrow, and located on median ridge. Adductor scars may be divided anteriorly by a low, narrow ridge (0.2 mm wide), located on surface of median ridge. Muscle field bounded laterally and anteriorly by strong muscle bounding ridges that begin slightly forward of teeth. Initially divergent, muscle bounding ridges quickly and sharply turn inwards, rapidly gaining height. Height decreases towards median ridge, but increases again upon joining with median ridge. A rounded peak may be formed where muscle-bounding ridges meet. A subperipheral ridge extends around valve edge, joining with dorsally directed tongue anteriorly. Hinge line faintly denticulate for most of length. Inner surface pseudopunctate, especially adjacent to muscle bounding ridges. Faint impressions of external rugae may also be visible.

Dorsal valve interior with erect and strongly bilobed cardinal process. Each lobe of cardinal process oval in cross-section and in some specimens with faint striations along their elongately flattened posterior edge. Sockets shallow, triangular impressions lying adjacent to cardinal process. Subtriangular median ridge short and low, extending forward from cardinal process, rapidly narrowing anteriorly; anterior point of median ridge extended in some specimens and in one bifurcates anteriorly. Adductor scars subcircular, deeply impressed, and separated by median ridge. Two low, broad and gently arcuate anderidia diverge forward from medial portion of cardinal process at 100° and extend anteriorly slightly further than median ridge before fading out. Hinge line faintly denticulate. Inner surface coarsely pseudopunctate, especially adjacent to and on anderidia. Traces of rugae visible internally around valve edges.

Ventral valves		Dorsal valves	
width (mm)	length (mm)	width (mm)	length (mm)
42*		38*	
42*		32*	18
38*	15		14.5
38*		29*	
36*		22*	
34*	16	22*	
32*	21		
31.5	16		
31	12		
28*	17		
25*			

Table 3. Dimensions for *Notoleptaena adamantea* sp. nov. * Indicates dimensions estimated due to incomplete nature of recovered specimens.

Measurements. Dimensions are given in Table 3. Ventral valves average 34.3 mm in width and 16.2 mm in length. Dorsal valves average 28.6 mm in width and 16.3 mm in length.

Remarks. The specimens from the Murrindal Limestone conform to the diagnosis provided by Gill (1951) and Cocks & Rong (2000) for *Notoleptaena*. Generically diagnostic features include a dorsally directed tongue, the muscle field of the ventral being bounded laterally and anteriorly by strong muscle bounding ridges, a subperipheral ridge in the ventral valve, the presence of concentric rugae and a small dorsal valve muscle field. However, unlike previously described species of *Notoleptaena*, this species differs in having irregularly spaced concentric rugae (Fig. 6B, F, G, I, K), a diamond shaped muscle field in the ventral valve muscle field with triangular shaped diductor scars and a faintly denticulate hinge line (Fig. 6A, H, J, L).

Notoleptaena adamantea is further distinguishable from *N. linguifera* and *N. undulifera* by lacking any trace of radial costellae (Fig. 6B, F, G, I, K) or a pseudodeltidium (Fig. 6A, H, L), which may also be lacking in *N. otophera. Notoleptaena linguifera* differs further in possessing more strongly developed rugae. *Notoleptaena adamantea*, unlike *N. undulifera* and *N.* cf. *linguifera*, also possesses well-developed teeth (Fig. 6A, H, L). Whereas *N. linguifera* also possesses well-developed teeth, they lack the crenulations present on the teeth of *N. adamantea* (Fig. 6A, H, L). Dorsal valve interiors are known only for *N. undulifera, N. lingulifera* and *N.* cf. *linguifera*; these species and *N. adamantea* all possess a similar cardinal process, but the subtriangular median ridge of *N. adamantea* distinguishes it from the other three taxa (Fig. 6C, E, J).

An unnamed species of *Notoleptaena* from the Lochkovian Bell Shale of the Eldon Group of Tasmania was described by Gill (1950: 253) as being comparable with neither *N. linguifera* nor *N. otophera*. From the little information provided by Gill (1950), it is only possible to differentiate between the Bell Shale specimens and those from the Murrindal Limestone on the basis of their cardinal extremities. The specimens from the Eldon Group possess non-alate cardinal extremities, whereas those of *N. adamantea* are variably alate (Fig. 6A, E, G, I, K). A second unnamed species of *Notoleptaena*, described by Talent (1965b) from the Stoddart Member of the Mount Ida Formation of Victoria, was referred to *N. otophera* by Talent et al. (2001).

Family DOUVILLINIDAE Caster, 1939
Subfamily PROTODOUVILLININAE Harper & Boucot, 1978b

Cymostrophia (Protocymostrophia) Harper & Boucot, 1978b

Type species. By original designation of Caster (1939: 148); *Leptaena stephani* Barrande, 1848; Lochkovian Kotýs Limestone, Svaty Jan pod Skalou, Czech Republic.

Remarks. Protocymostrophia was erected by Harper & Boucot (1978b) as a subgenus of *Mesodouvillina* for mesodouvillinids that are moderately to strongly concavo-convex and possess an ornament similar to *Cymostrophia*, features lacking in the other subgenera, *M.* (*Mesodouviella*) and *M.* (*Mesodouvillina*). Whereas Harper & Boucot (1978b) recognised many similarities between *M.* (*Protocymostrophia*) and *M.* (*Mesodouvillina*), they also noted a number of similarities with *Cymostrophia*, including ornament and well-developed brace plates. According to Harper & Boucot (1978b) these commonalities rarely occur in other mesodouvillinids and Rong & Cocks (1994) stated that such characteristics are important for differentiating strophomenid genera. This no doubt led Rong & Cocks (1994) and Cocks & Rong (2000) to reclassify *M.* (*Protocymostrophia*) as a subgenus of *Cymostrophia*.

According to Cocks & Rong (2000), *C.* (*Protocymostrophia*) is distinguishable from *C.* (*Cymostrophia*) by its suboval outline, gently concavo-convex profile and weakly developed interrupted rugae. *Cymostrophia* (*Cymostrophia*) possesses a more transverse outline, a strongly convex profile and strongly developed interrupted rugae.

Cymostrophia (Protocymostrophia) dickinsi
(Chatterton, 1973)
Fig. 7A-E

Cymostrophia dickinsi sp. nov. Chatterton 1973: 37, pl. 5, figs 31–33; pl. 6, figs 1–9; pl. 7, figs 1–12; pl. 13, figs 1–5.
Cymostrophia multicostella sp. nov. Chatterton 1973: 42, pl. 6, figs 10–16.
?*Mesodouvillina* (*Protocymostrophia*) cf. *dickinsi*- Brock & Talent 1993: 235; fig. 11A, B.

Material. Figured material: AM F117250 (Fig. 7A, B): articulated specimen from McL 417; AM

F117251 (Fig. 7C): ventral valve from ROC 159; AM F117252 (Fig. 7D): ventral valve from ROC 162; AM F117253 (Fig. 7E): dorsal valve fragment from ROC 159. Unfigured material: 42 ventral valves, 17 dorsal valves and 13 articulated specimens.

Description. See Chatterton (1973: 42).

Remarks. Chatterton (1973) assigned two new species, *C. dickinsi* and *C. multicostella*, from the Emsian '*Receptaculites*' Limestone Member to *Cymostrophia*, as they agreed the description provided by Caster (1939: 148) for *Cymostrophia*. Chatterton (1973) noted, however, these species differed from Havlíček's (1967: 126) diagnosis for *Cymostrophia* in possessing a convex, rather than a flat, pseudodeltidium, a feature Chatterton (1973) did not regard as generically significant. Harper & Boucot (1978b) subsequently reassigned both species to *Mesodouvillina* (*Protocymostrophia*) as they lacked a notably transverse outline and the trail was not as long as the central disk, an assessment also followed by Brock & Talent (1993). However, as discussed above, both species of Chatterton's (1973) are reassigned to *Cymostrophia* herein.

Brock & Talent (1993) also synonymised *C.* (*P.*) multicostella with *C.* (*P.*) *dickinsi*, although Chatterton (1973) had separated them on slight differences in size, number of costellae, strength of the rugae, position of maximum width of the diductor scars and how much of the hinge line was denticulate. This synonymy appears justified as *C.* (*P.*) *multicostella* is merely a smaller version of *C.* (*P.*) *dickinsi*.

Cymostrophia (*Protocymostrophia*) *ivanensis* (Barrande, 1879) closely resembles *C.* (*P.*) *dickinsi* externally, except that a greater portion of *C.* (*P.*) *ivanensis* is covered with rugae (Barrande 1879). The ventral valve muscle field of *C.* (*P.*) *ivanensis* tends to be more triangular in outline than that of *C.* (*P.*) *dickinsi* and is only divided by a fine myophragm, rather than a grooved median ridge. The dorsal valve muscle field of *C.* (*P.*) *dickinsi* is divided by a variably developed median ridge, whereas that of *C.* (*P.*) *ivanensis* is crossed by two narrow and slightly anteriorly divergent ridges which have a median septum located between them (Barrande 1879).

Cymostrophia (*Protocymostrophia*) has also been recovered from the Emsian Ukalunda Beds of Queensland (Brock & Talent 1993). Brock & Talent (1993) tentatively referred their material to *C.* (*P.*) *dickinsi* due to variation in outline and size of the ventral valve muscle field compared with that described by Chatterton (1973).

Subfamily PROTODOUVILLININAE Harper & Boucot, 1978b

Malurostrophia Campbell & Talent, 1967

Type species. By original designation of Campbell & Talent (1967: 309); *Malurostrophia flabellicauda* Campbell & Talent, 1967; early Emsian *Receptaculites* Limestone Member of the Taemas Limestone, Taemas, New South Wales, Australia.

Malurostrophia sp. cf. **M. flabellicauda** Campbell & Talent, 1967
Fig. 8G-K

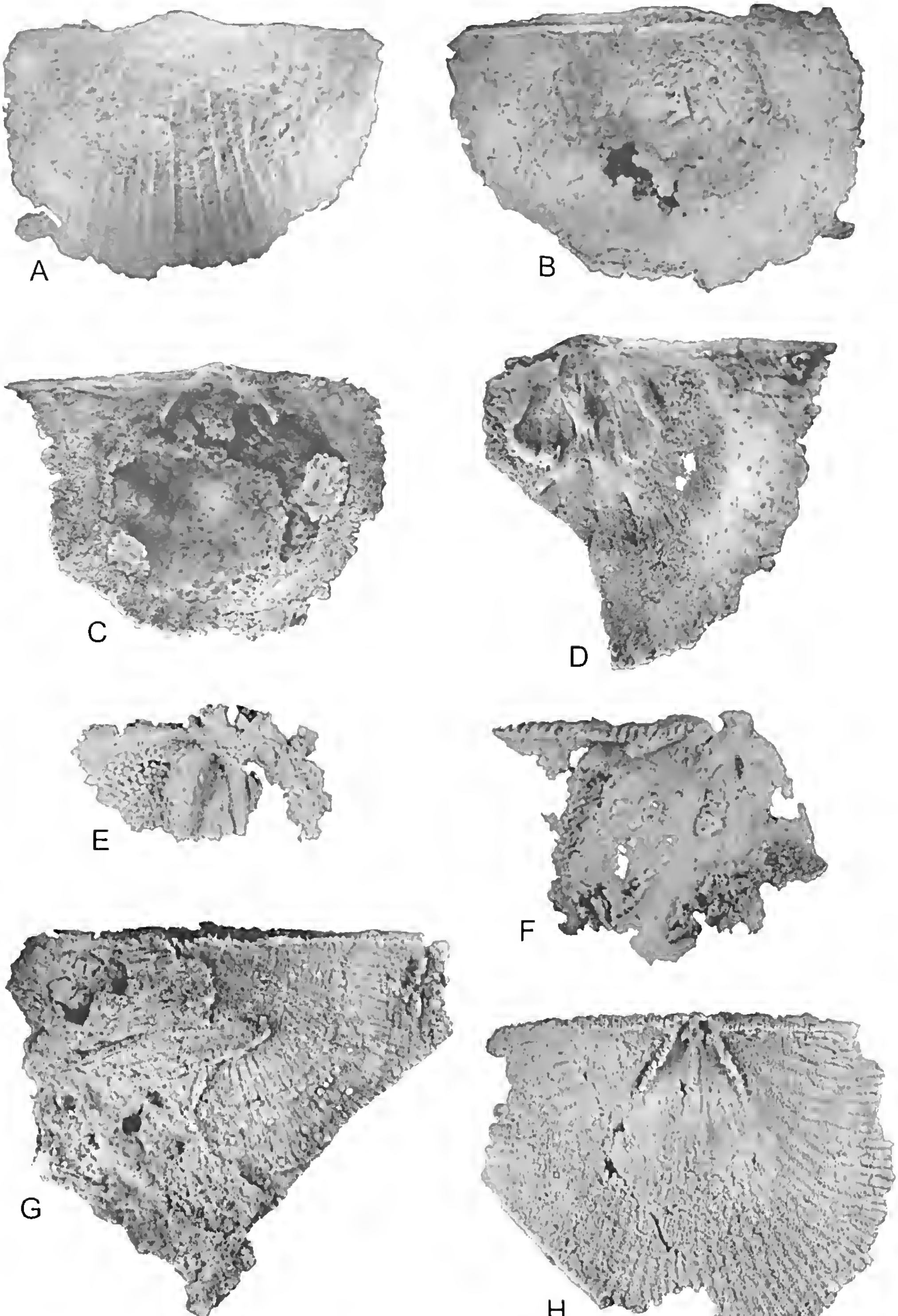
cf. *Malurostrophia flabellicauda* sp. nov. Campbell & Talent 1967: 311, pl. 47, figs 1–16; pl. 48, figs 1–20; pl. 49, figs 1–8; pl. 50, figs 8–10.
?*Malurostrophia flabellicauda reverta* subsp. nov. Chatterton 1973: 50, pl. 9, figs 1–10.
cf. *Malurostrophia minima* sp. nov. Chatterton 1973: 52, pl. 10, figs 11–29.
?*Malurostrophia aura* sp. nov. Chatterton 1973: 54, pl. 10, figs 1–10.
?*Malurostrophia bella* sp. nov. Chatterton 1973: 55, pl. 11, figs 1–17.

Material. Figured material: AM F117259 (Fig. 8G, H): ventral valve from ROC 159; AM F117260 (Fig. 8I, J): articulated specimen from ROC 159. AM F126346 (Fig. 8K): ventral valve from ROC 176.9. Unfigured material: one ventral valve and three articulated specimens.

Description. See Chatterton (1973: 52).

Remarks. Chatterton (1973) described three new species of *Malurostrophia*, *M. bella*, *M. aura* and

Fig. 7. A-E, *Cymostrophia (Protocymostrophia) dickinsi* (Chatterton, 1973). A, B, dorsal and ventral views of articulated specimen, McL 417, AM F117250, x 2. C, ventral valve interior, ROC 159, AM F117251, x 2. D, ventral valve interior, ROC 162, AM F117252, x 2. E, cardinal process, ROC 159, AM F117253, x 4. F-H, *Mesoleptostrophia* (*Paraleptostrophia*) *clarkei* (Chatterton, 1973). F, dorsal valve interior, McL 420dh, AM F117254, x 5. G, dorsal view of articulated specimen, ROC 159, AM F117255, x 2. H, ventral valve interior, ROC 159, AM F117256, x 2.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M. minima and a new subspecies of *M. flabellicauda*, *M. flabellicauda reverta*, from the Emsian '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas. Chatterton (1973) differentiated these species on size, length from the ventral valve beak to the beginning of the dorsal deflection of the anteriomedian portion of the shell, the degree of alation, the angle formed by the cardinal setal grooves with the hinge line, the presence or absence of a dorsal reversal in the growth of the lateral margins and the height to width and length to width ratios.

Although the specimens recovered from the Murrindal Limestone fall within the range of characteristics provided by Chatterton (1973) for *M. minima*, Talent et al. (2001) considered Chatterton's (1973) *Malurostrophia* species to be junior synonyms of *M. flabellicauda*. Examination of topotype material from Taemas confirms this observation. Indeed, the differences Chatterton (1973) used to distinguish the species are minor and the species appear to intergrade-*M. minima* to *M. flabellicauda* to *M. aura* to *M. flabellicauda reverta* and *M. bella*. In addition, Chatterton (1973) also mentioned the presence of intermediate forms that appear to link *M. minima* with *M. flabellicauda* and *M. flabellicauda* with *M. bella*.

Definite species allocation of the Murrindal specimens, however, is not possible due to previously unobserved morphological variations. The ventral valve muscle field of the Murrindal specimens ranges from 'waisted' (Fig. 8H) to 'non-waisted' (Fig. 8K), with the muscle field of 'waisted' forms being more strongly bilobate than the muscle field of 'non-waisted' forms (Fig. 8H, K). Only one of Campbell & Talent's (1967: pl. 49, fig. 5) specimens shows any 'waisting' of the ventral valve muscle field and this is only very weakly developed. Secondly, not all the Murrindal specimens are alate like those recovered by Chatterton (1973) and Campbell & Talent (1967) (Fig. 8H, J, K). Finally, the Murrindal specimens vary in their degree of resupination — alate forms are not as resupinate as non-alate forms.

The only other Early Devonian occurrence of *Malurostrophia* is *M. basilica* Campbell & Talent, 1967 from the Emsian Taravale Formation at Buchan, Victoria. This species differs from *M. flabellicauda* in its greater size and in having less strongly developed ornament. Internally, *M. basilica* has more sinuous muscle bounding ridges in the dorsal valve than *M. flabellicauda* and the node at the anterior margin of the dorsal valve adductor scars is more strongly expressed (Campbell & Talent 1967).

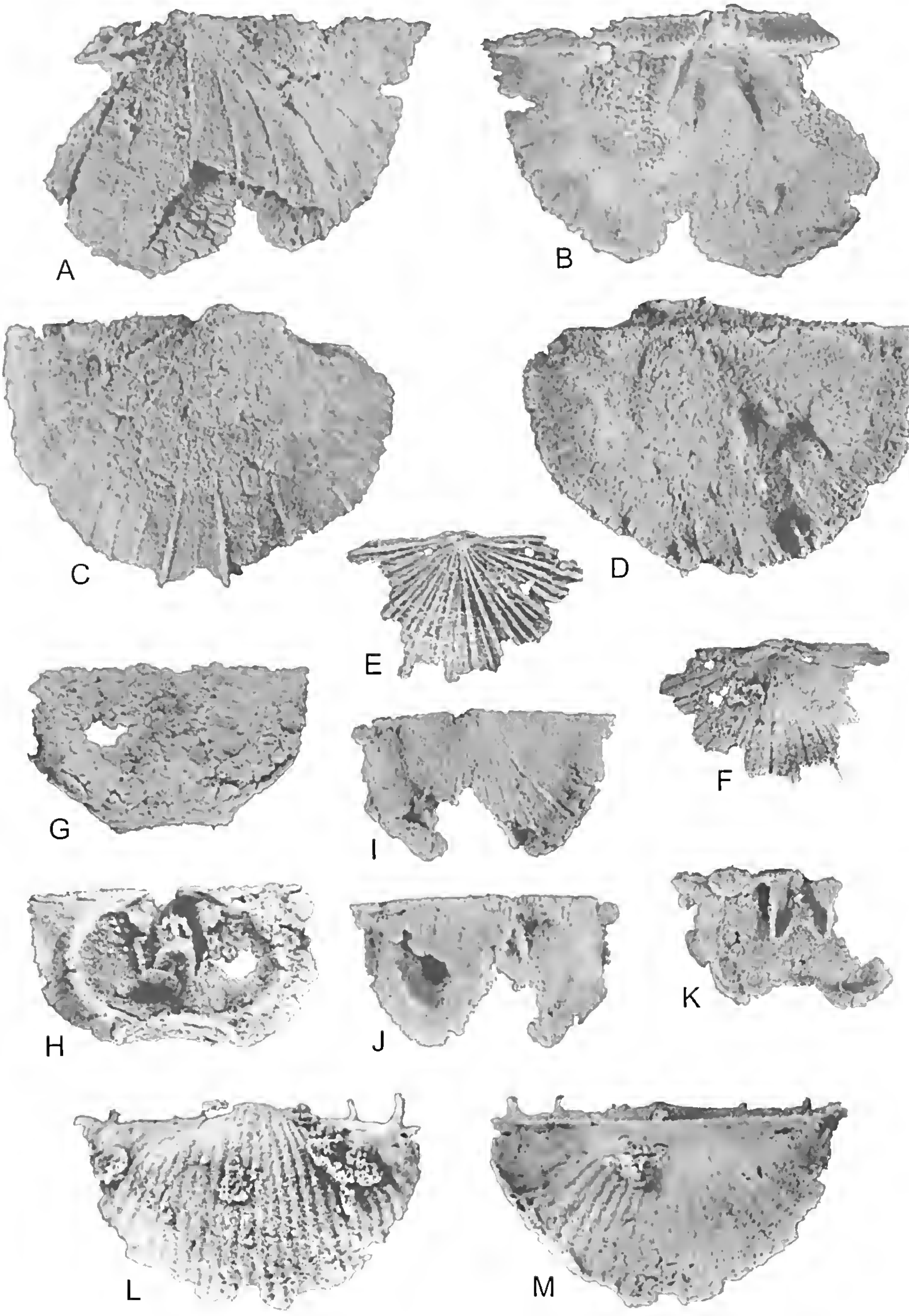
Nadiastrophia Talent, 1963

Type species. By original designation of Talent (1963: 62); *Nadiastrophia superba* Talent, 1963; Pragian Lower Kilgower Member of the Tabberabbera Formation, Victoria, Australia.

Remarks. Brock & Talent (1993) considered *Taemostrophia* Chatterton, 1973 a junior synonym of *Nadiastrophia*, contrary to Chatterton (1973) and Harper & Boucot (1978b), who accepted both genera on the basis that the ventral valve muscle field of *Taemostrophia* differed by being 'waisted'. From their study of specimens from the Emsian Ukalunda Beds and Douglas Creek of Queensland, Brock & Talent (1993) concluded that this feature is highly variable. Parfrey's (1989: pl. 1, figs 4–6) figures of *Taemostrophia* from the same area also show similar variation, whereas the single specimen figured by Hill et al. (1967: pl. D12, fig. 3), only shows slight 'waisting' of the ventral valve muscle field. Close examination of Chatterton's (1973: pl. 8, figs 1–19; pl. 13, figs 6–9) figures also reveals a high degree of variability in this feature. All specimens from the Murrindal Limestone assigned to *Nadiastrophia* lack this feature. Chatterton (1973) and Harper & Boucot (1978b) also suggested that *Taemostrophia* can be differentiated externally from *Nadiastrophia* by having a slightly raised central disk in the ventral valve and by being slightly depressed along the geniculate rim. Talent (1963: 62), however, described *Nadiastrophia* as possessing a slightly raised umbonal region in the ventral valve, which slopes towards the point of geniculation. Therefore, *Taemostrophia* should be considered synonymous with *Nadiastrophia*.

According to Wang (in Wang et al. 1974), the type species of *Xenostrophia*, *X. yukiangensis*

Fig. 8. A-D. *Nadiastrophia patmorei* (Chatterton, 1973). All specimens x 5. A, B, ventral valve exterior and interior, ROC 159, AM F117257. C, D, ventral and dorsal views of articulated specimen, ROC 159, AM F117258. E, F, *Eoschuchertella murphyi* (Chatterton, 1973), dorsal valve interior and exterior, ROC 165, AM F117261, x 5. G-K, *Malurostrophia* sp. cf. *M. flabellicauda* Campbell & Talent, 1967. All specimens x 5. G, H, ventral valve exterior and interior, ROC 159, AM F117259. I, J, ventral and dorsal views of articulated specimen, ROC 159, AM F117260. K, ventral valve interior, ROC 176.9, AM F126346. L, M, *Johnsonetes australis* (McCoy, 1876), ventral and dorsal views of articulated specimen, ROC 165, AM F117262, x 5.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(Wang, 1956) from the Emsian Yükiang Formation of Kwangsi Province, China, differs from *Nadiastrophia* by being larger, having a less prominent beak, a widely rectangular ventral valve muscle field, shallow pallial markings and having a dorsal valve muscle field which is not elevated on a platform. Harper & Boucot (1978b), however, referred *X. yukiangensis* to *Nadiastrophia*. Examination of the ventral valve muscle field of *X. yukiangensis* shows its outline to be variable. The ventral valve muscle field of the two specimens figured by Wang et al. (1974: pl. 5, figs 4, 5) differs from the ventral muscle field of *N. superba* in being longer, broader and in having the widest point located behind valve midlength. On the other hand, the ventral valve muscle field of the specimen figured by Hou & Zian (1975: pl. 5, fig. 10) is more in keeping with *Nadiastrophia* than *Xenostrophia*, being shorter and thinner, with the widest point at the midlength. Rong & Cocks (1994) believed that generic distinction amongst strophomenoids can only be made on internal features, including the presence or absence of dental or socket plates, muscle bounding ridges, side septa or diaphragms; character states like ornament, dimensions, shell shape and the relative proportion of internal structures can be useful discriminators at the species level. *Xenostrophia* can be questionably considered synonymous with *Nadiastrophia*.

Nadiastrophia patmorei (Chatterton, 1973)
Fig. 8A-D

Nadiastrophia sp. nov. Hill, Playford & Woods 1967: pl. D12, figs 3, 4.
Taemostrophia patmorei sp. nov. Chatterton 1973: 44, pl. 8, figs 1–9; pl. 13, figs 6–9.-Harper & Boucot 1978b: 143, pl. 28, figs 11, 13–16.-Parfrey 1989: pl. 1, figs 1, 2, 4, 7.
Nadiastrophia patmorei-Brock & Talent 1993: 235, fig. 10P-T.

Material. Figured material: AM F117257 (Fig. 8A, B): ventral valve from ROC 159; AM F 117258 (Fig. 8C, D): articulated specimen from ROC 159. Unfigured material: 31 ventral valves and five articulated specimens.

Description. See Chatterton (1973: 44).

Remarks. Nadiastrophia superba from the Pragian Lower Kilgower Member of the Tabberabbera Formation, Victoria (Talent 1963), the Pragian Garra Limestone (Lenz & Johnson 1985a) and the Lochkovian Garra Limestone at Eurimbla, New South Wales (Brock 2003a), closely resembles *N. patmorei* from several Emsian localities of eastern Australia (see Hill et al. 1967: d.24; Chatterton 1973: 43; Parfrey 1989: 201; Brock & Talent 1993: 231). They differ, however, in that *N. superba* possesses a more strongly bilobate muscle field in the ventral valve and a greater proportion of the hinge line is denticulate (almost whole length versus half). The dorsal valve of *N. superba* has a laterally directed cardinal process, whereas the lobes are ventrally directed in *N. patmorei* and the socket ridges of *N. superba* diverge at a slightly shallower angle than in *N. patmorei*.

Numerous species of *Nadiastrophia* have been described from Early and Middle Devonian strata of China (see Wang et al. 1987 and Chen et al. 1989 and references therein). They tend to differ from both *N. patmorei* and *N. superba* in possessing less well-developed costellae and are not as strongly transverse or alate. Most also possess a more strongly bilobate ventral valve muscle field than *N. patmorei* and also tend to lack the degree of variation observed by Hill et al. (1967), Chatterton (1973), Parfrey (1989) and Brock & Talent (1993) in the muscle field outline of the ventral valve.

Nadiastrophia insignis Kaplun (in Kaplun & Krupchenko, 1991), from the Lower Devonian Balkhash region of Kazakhstan, is similar to *N. patmorei* externally, although it is not as transverse or alate. However, the ventral valve muscle field of *N. insignis* appears to be variably bilobate, extending for most of the valve length, and lacks evidence of 'waisting'. In addition, the ventral valve muscle field of *N. insignis* is bounded posteriorly and anteriorly by ridges.

Harper et al. (1967: 425) also mentioned the possible occurrence of *Nadiastrophia*, based on a single internal mould of a ventral valve, from the early Emsian Reefton Group of New Zealand. As Harper et al. (1967) did not describe or figure this species, comparisons are not possible.

Family LEPTOSTROPHIIDAE Caster, 1939

Mesoleptostrophia (Paraleptostrophia) Harper & Boucot, 1978a

Type species. By original designation of Harper & Boucot (1978a: 70); *Leptostrophia clarkei* Chatterton, 1973; early Emsian Warroo Limestone Member of the Taemas Limestone, Taemas, New South Wales, Australia.

Remarks. Harper & Boucot (1978a) erected *Mesoleptostrophia* for gently concavo-convex leptostrophiinids with socket plates and a triangular muscle field in the ventral valve bounded laterally by ridges. Harper & Boucot (1978a) also divided *Mesoleptostrophia* into two subgenera, *M.* (*Mesoleptostrophia*), which has divergent socket plates relative to the lateral margins of the cardinal process and *M.* (*Paraleptostrophia*), which possesses socket plates lying parallel to the lateral margins of the cardinal process. Cocks & Rong (2000) separated these genera primarily on the basis of the cardinal process lobes-strongly posteriorly directed in *M.* (*Paraleptostrophia*) and relatively small and ventro-posteriorly directed in *M.* (*Mesoleptostrophia*).

Unlike *M.* (*Mesoleptostrophia*), *M.* (*Paraleptostrophia*) has a relatively restricted distribution, occurring only in Burma (Reed 1908; Anderson et al. 1969; Harper & Boucot 1978a) and Kazakhstan (Kaplun & Krupchenko 1991), in addition to Australia.

Mesoleptostrophia (Paraleptostrophia) clarkei
(Chatterton, 1973)
Fig. 7F-H

?*Leptostrophia* sp. Whitehouse 1929: 159.

Leptostrophia clarkei sp. nov. Chatterton 1973: 58, pl. 12, figs 1–13; pl. 13, figs 10–17; pl. 35, figs 12–14.

Mesoleptostrophia (*Paraleptostrophia*) *clarkei*-Parfrey 1989: pl. 1, figs 7–17, 19–21.-Brock & Talent 1993: 236, fig. 10U, V.

Material. Figured material: AM F117254 (Fig. 7F): dorsal valve from McL 420dh; AM F117255 (Fig. 7G): articulated specimen from ROC 159; AM F117256 (Fig. 7H): ventral valve from ROC 159. Unfigured material: 29 ventral valves, seven dorsal valves and four articulated specimens.

Description. See Chatterton (1973: 58).

Remarks. Harper & Boucot (1978a) reassigned *Leptostrophia clarkei* from the Emsian '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas (Chatterton 1973) and the Emsian Ukalunda Beds and Douglas Creek of Queensland (Whitehouse 1929; Parfrey 1989; Brock & Talent 1993) to *M.* (*Paraleptostrophia*), based on the socket plates of this species lying subparallel to the lateral margins of the cardinal process lobes. Specimens from the Murrindal Limestone are in general poorly preserved, the dorsal valves in particular, but the socket plates are still observable and lie subparallel to the lateral margins of the cardinal process (Fig. 7F).

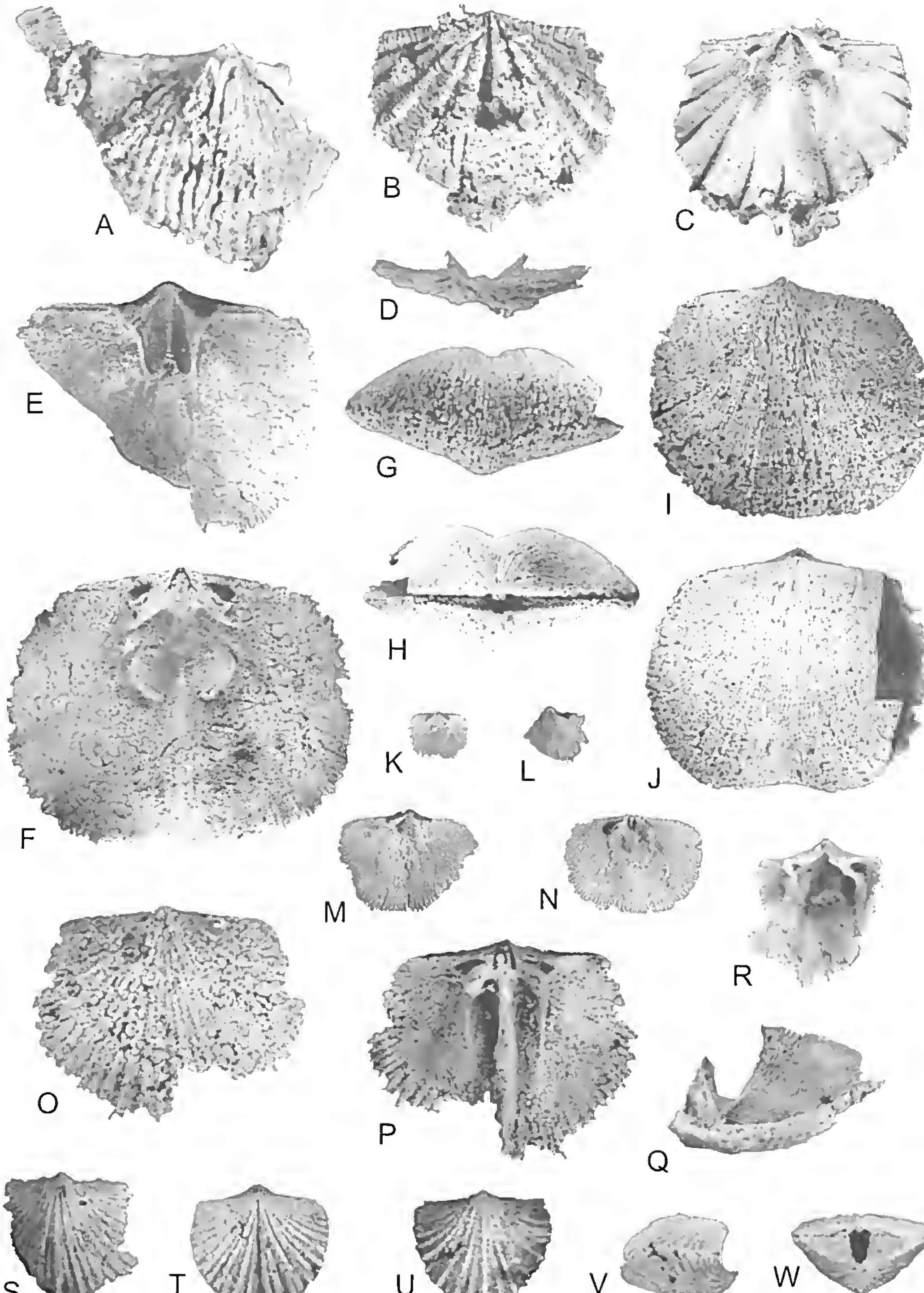
In his original description of *M.* (*P.*) *clarkei*, Chatterton (1973) did not mention the bilobed nature of the muscle field in the ventral valve. Although this feature appears to be variable, it is clearly observable in Chatterton's (1973: pl. 12, fig. 1; pl. 13, figs 16, 17) figured material. A variably bilobate ventral valve muscle field also occurs in specimens from the Emsian Ukalunda Beds and Douglas Creek of Queensland (see Parfrey 1989: pl. 1, figs 8, 9, 16 and Brock & Talent 1993: fig. 10U, V). Material from the Murrindal Limestone also displays some degree of bilobation to the ventral valve muscle field (Fig. 7H).

Externally, *M.* (*P.*) *clarkei* is very similar to *M.* (*P.*) *padaukpinensis* Anderson, Boucot & Johnson, 1969, from the Eifelian Padaukpin Limestone of Burma, although the ornament of *M.* (*P.*) *clarkei* is slightly coarser. Both valves of *M.* (*P.*) *padaukpinensis* possess only short myophores, whereas both valves of *M.* (*P.*) *clarkei* have a median ridge. *Mesoleptostrophia* (*Paraleptostrophia*) *lepsensis* Krupchenko (in Kaplun & Krupchenko, 1991), from the Early Devonian northern Balkhash region of Kazakhstan, has a greater proportion of its hinge line covered with denticles than *M.* (*P.*) *clarkei* (full length versus three-quarters); the muscle scars, though similar in outline, are not as deeply impressed as in *M.* (*P.*) *clarkei*.

Order PRODUCTIDA Sarytcheva & Sokolskaya, 1959
Suborder CHONETIDINA Muir-Wood, 1955
Superfamily CHONETOIDEA Bronn, 1862
Family STROPHOCHONETIDAE Muir-Wood, 1962
Subfamily STROPHOCHONETINAE Muir-Wood, 1962

Johnsonetes Racheboeuf, 1987

Type species. By original designation of Racheboeuf (1987: 7); *Chonetes filistriata* Walcott, 1884; Emsian of Comb's Peak, Eureka District, Nevada, America.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Johnsonetes australis (McCoy, 1876)
Fig. 8L, M

Chonetes australis sp. nov. McCoy 1876: 141, pl. 35, figs 3–5.-Gill 1951: 64, pl. 3, figs 18, 19, 21.-Talent 1956a: 41, pl. 3, figs 10, 11.
Chonetes teicherti sp. nov. Gill 1951: 70, pl. 3, figs 12–15.
?Protochonetes sp. Brock & Talent 1993: 236, fig. 11C-E.
Johnsonetes australis-Strusz 2000: 257, figs 8, 9.

Material. Figured material: AM F117262 (Fig. 8L, M): articulated specimen from ROC 165. Unfigured material: 23 ventral valve fragments and 12 articulated specimens.

Description. See Gill (1951: 64), Talent (1956a: 41) and Strusz (2000: 257).

Remarks. Following Strusz (2000), this species is assigned to *Johnsonetes* as the hinge spines are inserted asymmetrically and spine 1' is absent, the cardinal process is supported by anteriorly divergent, rounded, inner socket ridges and the median costa is enlarged only posteriorly. *Johnsonetes australis* is distinguishable from *J. filistriata* in possessing a greater number of hinge spines and fewer, coarser costae that increase in number occasionally by bifurcation. No trace of the faint undulating concentric striae observed by Walcott (1884) and illustrated by Johnson (1970a: pl. 31, figs 9, 12) in *J. filistriata*, are present in *J. australis*.

Johnsonetes australis is closely related to *J. culleni* (Dun, 1904) from the Emsian '*Spirifer*' yassensis, '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas. Both have a similar size, shape, tendency to develop a weak ventral valve sulcus and a prominent notothyrial platform (Strusz 2000). Dun (1904) confidently separated the two on the basis that *J. culleni* is more strongly convex, possesses fewer and coarser ribs and is less flattened towards the cardinal angles, but Chatterton (1973) regarded *J. culleni* as possibly being synonymous with *J. australis*. He differentiated them by the anderidia of *J. australis* being located on a pair of low ridges and the socket ridges being more prominent than those of *J. culleni*. Brock & Talent (1993) and Talent et al. (2001) considered *J. culleni* synonymous with *J. australis* and the observed differences a result of intraspecific variation. However, despite rejecting the differences cited by Dun (1904), Strusz (2000) considered *J. australis* and *J. culleni* distinct. In addition to the differences observed by Chatterton (1973), Strusz (2000) stressed the flat ventral valve interarea and the prominent protegular structures of the dorsal and ventral valves in *J. australis* and the weakly concave ventral valve interarea of *J. culleni* and obscure protegular structures of both valves.

Johnsonetes australis is so similar to *J. latus* (Chatterton, 1973) from the Emsian '*Receptaculites*' Limestone Member of the Taemas Limestone at Taemas, that Talent et al. (2001) synonymised *J. latus* with *J. australis*. However, Strusz (2000) considered *J. latus* distinct, being small, transverse with distinctly triangular alae and having few hinge spines and deep furrows developed between the ribs. Internally, strongly developed anderidia and the median septum are fused to a prominent notothyrial platform (Strusz 2000).

Johnsonetes australis is also closely related, possibly even synonymous with, an unnamed species referred to *Protochonetes* Muir-Wood, 1962 by Brock & Talent (1993) from the Emsian Ukalunda Beds and Douglas Creek of Queensland. They are similar in size, the development of a sulcus in the ventral valve and internal features of the ventral valve. However, the adductor muscle scars in the ventral valve of *P. australis* tend to be more divergent (Brock & Talent 1993) and the ventral valve median septum to be thicker and shorter. The interior of the dorsal valve and the nature of the hinge spines are not known in the specimens from the Ukalunda Beds and Douglas Creek (Strusz 2000).

Strusz (2000) questionably referred *?Devonochonetes* sp. 2 of Lenz and Johnson (1985a) from the Pragian Garra Limestone at Wellington to

Fig. 9. A, *Johnsonetes*? sp. cf. *J. culleni* (Dun, 1904), dorsal valve interior, ROC 165, AM F117263, x 5. B-D, Hesperorthidae gen. et sp. indet., exterior, interior and posterior views of dorsal valve, ROC 174.1, AM F117264, x 4. E-N, *Tyersella spedeni* Chatterton, 1973. All specimens x 2. E, ventral valve interior, ROC 181, AM F117265. F, dorsal valve interior, ROC 181, AM F117266. G-J anterior, posterior, ventral and dorsal views of articulated specimen, ROC 181, AM F117267. K, dorsal valve interior, ROC 159, AM F126347. L, ventral valve interior, ROC 159, AM F126348. M, ventral valve interior, ROC 159, AM F126349. N, dorsal valve interior, ROC 159, AM F126350. O-W, *Prokopia hillae* (Chatterton, 1973). All specimens x 6. O-Q, exterior, internal and lateral views of dorsal valve, ROC 174.1, AM F117268. R, S, ventral valve interior and exterior, McL 420dh, AM F117269. T-W, dorsal, ventral, lateral and posterior views of articulated specimen, McL 420dh, AM F117270.

Johnsonetes on the presence of a prominent notothyrial platform, wide cardinal process, a well-developed dorsal valve medium septum and a weakly impressed ventral valve muscle field. It thus closely resembles both *J. australis* and *J. culleni*, but *J. australis* is larger and more coarsely ornamented (Strusz 2000).

Johnsonetes ellesmerensis Racheboeuf, 1987, from the Emsian lower member of the Blue Fiord Formation, Ellesmere Island in the Canadian Arctic Archipelago, is smaller and less strongly concavo-convex than *J. australis*. Internally, *J. ellesmerensis* has a shorter median septum in the dorsal valve and anderidia that are not located on broad ridges. *Johnsonetes arcticus* Racheboeuf, 1987, which occurs higher in the Blue Fiord Formation, may be distinguished from *J. australis* by its larger size, concave ventral interarea and slightly more numerous ribs. Internally, it can be distinguished by teeth which are oval in cross section, a weakly bilobed cardinal process, anderidia that are not located on broad ridges, and by the lack of papillae on the inner surface of the dorsal valve.

Johnsonetes? sp. cf. **J. culleni** (Dun, 1904)
Fig. 9A

?*Chonetes culleni* sp. nov. Dun 1904: 321, pl. 61, figs 1, 1a.
?*Protochonetes culleni*-Chatterton 1973: 69, pl. 16, figs 1–22.
?*Johnsonetes culleni*-Strusz 2000: 260, figs 9, 10.

Material. Figured material: AM F117263 (Fig. 9A): dorsal valve from ROC 165.

Description. See Chatterton (1973: 69) and Strusz (2000: 260).

Remarks. The long, posteriorly widened median septum of the dorsal valve, short, wide cardinal process to which anteriorly divergent anderidia are fused, and low rounded socket ridges of this specimen (Fig. 9A) are all reminiscent of *Johnsonetes*, particularly *J. australis* and *J. culleni*. The well-developed alae of this specimen suggest that its affinities lie with *J. australis* but, as the anderidia are not raised on ridges, its affinities therefore appear to lie with *J. culleni*. However, as no hinge spines or bases have been preserved in this specimen (Fig. 9A), its assignment to *Johnsonetes* must remain doubtful.

Order ORTHOTETIDA Waagen, 1884
Suborder ORTHOTETIDINA Waagen, 1884
Superfamily CHILIDIOPSOIDEA Boucot, 1959
Family AREOSTROPHIIDAE Manankov, 1979
Subfamily ADECTORHYNCHINAE Henry & Gordon, 1985

Eoschuchertella Gratsianova, 1974

Type species. By original designation of Gratsianova (1974: 83); *Eoschuchertella popovi* Gratsianova, 1974; late Emsian Malokorgonsk beds of Gorno-Altai, southwestern Siberia, Russia.

Remarks. Eoschuchertella was proposed by Gratsianova (1974) to separate impunctate forms resembling the pseudopunctate *Schuchertella* Girty, 1904. It is upon this basis that the following species has been reassigned to *Eoschuchertella*.

Eoschuchertella murphyi (Chatterton, 1973)
Fig. 8E, F

Schuchertella murphyi sp. nov. Chatterton 1973: 63, pl. 14, figs 1–17.
?*Eoschuchertella* cf. *E. murphyi*-Perry 1979: pl. 1, figs 22–25.-?Perry 1984: 50, pl. 15, figs 13–19.

Material. Figured material: AM F117261 (Fig. 8E, F): dorsal valve from ROC 165. Unfigured material: two ventral valves and four dorsal valves.

Description. See Chatterton (1973: 63).

Remarks. Eoschuchertella popovi differs from *E. murphyi* in possessing fine costellae arising by bifurcation in both valves, whereas the costellae of *E. murphyi* are coarser and arise through both bifurcation and intercalation in both valves (Fig. 8F). Internally, *E. popovi* has a more strongly bilobate cardinal process than *E. murphyi* and a less strongly convex pseudodeltidium. The internal surface of *E. murphyi* is strongly and coarsely crenulate, especially around the margins (Fig. 8E), whereas the internal surface of *E. popovi* is more finely and evenly crenulate.

Eoschuchertella murphyi is very similar to *E. burrenensis* (Savage, 1971) from the Early Devonian Garra Limestone tongue at Manildra (Savage 1971), The Gap (Farrell 1992) and Eurimbla (Brock 2003a), particularly in possessing recurved socket

plates, features of the cardinalia, number and size of costellae, and the lack of dental lamellae (Chatterton 1973). Chatterton (1973) separated them primarily on the maximum size attained by mature individuals, with the largest specimens of *E. murphyi* from the Emsian '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas being less than half the size of some specimens figured by Savage (1971: pl. 73, figs 1–21). Despite only a small number of specimens having been recovered from the Murrindal Limestone, their size (the largest specimen recovered, although incomplete, measures 7 mm in width and 4 mm in length) suggests assignment to *E. murphyi*.

Eoschuchertella is a common component of Early and Middle Devonian strata throughout Canada and Alaska (Chatterton & Perry 1978). Perry (1984) documented three species of *Eoschuchertella* from the Pragian to Emsian sequences of the Delorme Formation, one of which was questionably referred to *E. murphyi*. Perry's (1984) *E.* sp. cf. *E. murphyi* and the Australian material are identical in terms of ornament, lack of dental lamellae and muscle scars. The Delorme specimens differ though in having only a weakly bilobed cardinal process, a feature regarded as being of taxonomic significance by Williams & Brunton (1993) and Brunton & Cocks (1996).

Another unnamed species of *Eoschuchertella* from the early Pragian Heceta Island of southeastern Alaska was described by Savage (1981) as being identical to *E. burrenensis* and to material described by Johnson (1970a) from Nevada and Lenz (1977a) from the Yukon.

Class RHYNCHONELLATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order ORTHIDA Schuchert & Cooper, 1932
Suborder ORTHIDINA Schuchert & Cooper, 1932
Superfamily ORTHOIDEA Woodward, 1852
Family HESPERORTHIDAE Schuchert & Cooper, 1931

Dolerorthis sp.
Fig. 10N-U

Material. Figured material: AM F117276 (Fig. 10N-R): articulated specimen from McL 417; AM F117277 (Fig. 10S, T): ventral valve from ROC 162; AM F117278 (Fig. 10U): dorsal valve from McL 417. Unfigured material: 11 ventral valves, one dorsal valve and four articulated specimens.

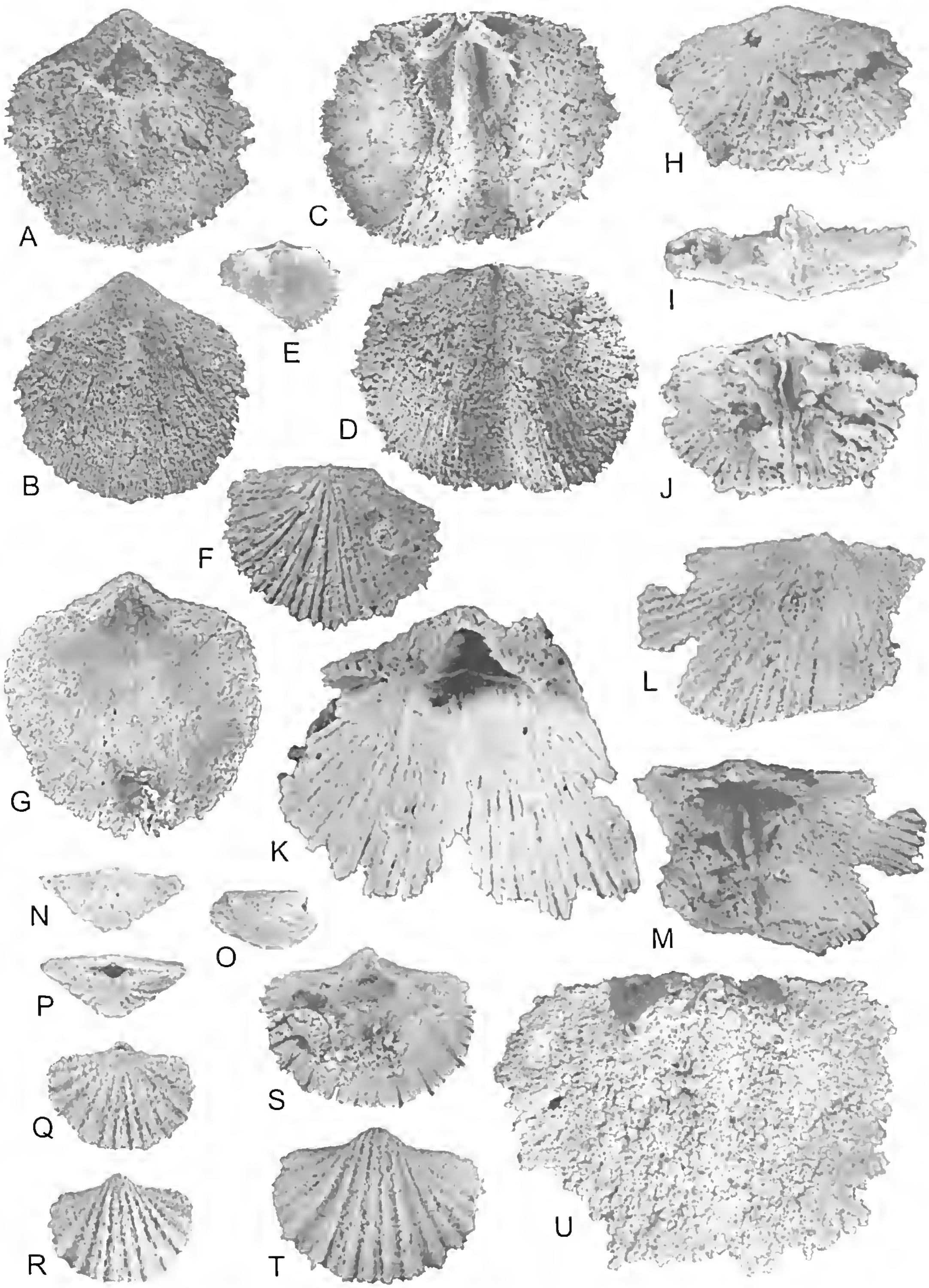
Remarks. The ventri-biconvex lateral profile, triangular apsacline ventral valve interarea with an open delthyrium (Fig. 10P, S) and dorsal valve with an anacline interarea and notothyrial platform bearing a blade-like cardinal process (Fig. 10U) indicates affinities with *Dolerorthis* (Schuchert & Cooper 1932; Amsden 1968, 1974; Johnson et al. 1973). However, unlike many other *Dolerorthis*, such as *D. borealis* Lenz, 1977a, from the upper Lochkovian and lower Pragian strata of the Delorme Formation (Lenz 1977a; Perry 1984) and the Lochkovian Garra Limestone at Wellington (Lenz & Johnson 1985a) and Eurimbla (Brock 2003a) and *D. ornata* Lenz & Johnson, 1985a from the Lochkovian Garra Limestone at Wellington, the Murrindal specimens lack third and fourth order costellae (Fig. 10Q, R, T). The first order costellae are well-developed and second order costellae arise at varying distances from the beak through bifurcation and intercalation. The Murrindal specimens differ further in possessing a curved ventral valve interarea cleft by a triangular delthyrium, rather than a slit-like delthyrium with subparallel margins (Fig. 10P, S), by lacking well-developed growth lamellae (Fig. 10Q, R, T) and by their smaller size (ventral valves average 5.33 mm wide and 4.04 mm long; dorsal valves average 5.81 mm wide and 4.06 mm long).

The Murrindal specimens are most similar to *D. persculpta* Philip, 1962 from the latest Lochkovian to earliest Pragian Boola siltstone of the Tyers-Boola area, central Victoria. Both species lack third and fourth order costellae and possess a curved ventral valve interarea cleft by a triangular delthyrium. The Murrindal specimens differ primarily from *D. persculpta* in their slightly smaller size, fewer primary costae and lack of growth lamellae. Additional material, particularly dorsal valves, are required before a more positive identification is possible.

Hesperorthidae gen. et sp. indet.
Fig. 9B-D

Material. Figured material: AM F117264 (Fig. 9B-D): dorsal valve from ROC 174.1.

Remarks. The internal features of this dorsal valve resemble *Dolerorthis* in possessing well-developed, divergent brachiophores, a simple ridge-like cardinal process, a low broad, indistinct median ridge extending to valve midlength and long narrow adductor scars (Fig. 9C). It differs from *Dolerorthis* though in possessing only primary costae (Fig. 9B). The costae of this specimen all arise in the beak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area, whereas the primary costae of *Dolerorthis* arise through bifurcation of and/or intercalation between those originating in the beak area. Zhang (1989) erected *Flabellitesia* for hesperorthids with simple costae, an antygidium and a dorsi-biconvex to resupinate profile. The Murrindal specimen though is flat in profile and lacks an antygidium (Fig. 9D). *Hesperorthis* Schuchert & Cooper, 1931, also possesses simple costae, but differs in possessing an antygidium as well.

This combination of features suggests the Murrindal specimen may represent a new genus of hesperorthid with simple costae and lacking an antygidium. Additional material is required to confirm this.

Suborder DALMANELLIDINA Moore, 1952
Superfamily DALMANELLOIDEA Schuchert, 1913
Family DALMANELLIDAE Schuchert, 1913
Subfamily ISORTHINAE Schuchert & Cooper, 1931

Tyersella Philip, 1962

Type species. By original designation of Philip (1962: 197); *Tyersella typica* Philip, 1962; Pragian Coopers Creek Formation, Tyers-Boola area, central Victoria, Australia.

Remarks. Philip (1962) noted that *Tyersella* was likely to be closely related to *Isorthis* due to similarities in ornament, muscle scars, cardinal process and the digitate dorsal pallial sinuses. Talent (1965b: 23) believed *Tyersella* was 'a typical Isorthid' and therefore considered *Tyersella* a subgenus of *Isorthis*. Despite Johnson et al. (1973: 18) claiming *Tyersella* was 'morphologically distinct from *Isorthis*', Walmsley & Boucot (1975) considered *Tyersella* a subgenus of *Isorthis*, based primarily on similarities between the muscle fields of both valves. They distinguished *I.* (*Tyersella*) from the other subgenera of *Isorthis*, *I.* (*Isorthis*), *I.* (*Protocortezortis*), *I.* (*Ovalella*) and *I.* (*Arcualla*), on features of the dorsal valve muscle field and the sockets being excavated in the valve floor. Havlíček (1977), Smith (1980), Kaplun & Krupchenko (1991) and Williams & Harper (2000) have all maintained *Tyersella* as a separate genus, which is followed here. This assessment is based on differences in shell convexity, the presence or absence of fulcral plates and differences in the dorsal valve muscle field.

Tyersella spedeni (Chatterton, 1973)
Fig. 9E-N

Isorthis spedeni sp. nov. Chatterton 1973: 19, pl. 1, figs 8–22; pl. 2, figs 1–14; pl. 5, figs 16–24; pl. 35, fig. 13.
?*Isorthis* sp. Parfrey 1989: pl. 1, fig. 3.
Isorthis (*Tyersella*) *spedeni*-Brock & Talent 1993: 233, fig. 91-O.

Material. Figured material: AM F117265 (Fig. 9E): ventral valve from ROC 181; AM F117266 (Fig. 9F): dorsal valve from ROC 181; AM F117267 (Fig. 9G-J): articulated specimen from ROC 181. AM F126347 (Fig. 9K): dorsal valve from ROC 159. AM F126348 (Fig. 9L): ventral valve from ROC 159. AM F126349 (Fig. 9M): ventral valve from ROC 159. AM F126350 (Fig. 9N): dorsal valve from ROC 159. Unfigured material: 238 ventral valves, 257 dorsal valves and 21 articulated specimens.

Description. See Chatterton (1973: 19).

Remarks. Tyersella typica is larger than *T. spedeni* and is nonsulcate. The dorsal valve median ridge of *T. typica* extends beyond the anterior margin of the muscle field (Brock & Talent 1993). In addition, *T. spedeni* differs from most other *Tyersella*, such as *T. concinna* (Hall, 1859b) and *T. perelegans* (Hall, 1857), in possessing a well-developed sulcus in the dorsal valve, and having sockets raised on secondary shell material, instead of being excavated in the valve floor.

Ontogeny. Neanic specimens of *T. spedeni* recovered from the Murrindal Limestone are ventribiconvex, with a variably developed shallow sulcus in the dorsal valve. Less than a dozen primary costellae are present with secondary costellae arising through

Fig. 10. A-G, *Resserella careyi* Chatterton, 1973. All specimens x 2. A, B, ventral valve interior and exterior, ROC 162, AM F117271. C, D, dorsal valve interior and exterior, ROC 162, AM F117272. E, ventral valve interior, ROC 159, AM F126351. F, dorsal valve exterior, ROC 159, AM F126352. G, ventral valve interior, ROC 159, AM F126353. H-M, *Biernatium catastum* sp. nov. All specimens x 8. H-J, holotype, exterior, posterior and interior views of dorsal valve, McL 520, AM F117274. K, ventral valve interior, McL 520, AM F117273. L, M, dorsal valve exterior and interior, McL 520, AM F117275. N-U, *Dolerorthis* sp. All specimens x 5. N-R, anterior, lateral, posterior, dorsal and ventral views of articulated specimen, McL 417, AM F117276. S, T, ventral valve interior and exterior, ROC 162, AM F117277. U, dorsal valve interior, McL 417, AM F117278.

intercalation and subdivision. The teeth are small, triangular and supported by short and strongly divergent dental plates. The ventral valve muscle field is bilobate, with the diductor scars being separated by a low ridge upon which the adductor scars are located, with no muscle bounding ridges (Fig. 9L). The cardinal process is simple and nonlobed. The brachiophores are strongly divergent and supported by small brachiophore plates that extend forward as low muscle bounding ridges. The midpoint of the muscle bounding ridges is notched, marking the boundary between the posterior and anterior pair of adductor scars that are otherwise indistinguishable. The sockets are variably raised on secondary shell material (Fig. 9K).

Sub-adult *T. spedeni* are subequally biconvex, the dorsal valve becoming more strongly convex compared to neanic specimens. The ventral valve muscle field is more firmly impressed and elongate than in neanic specimens and weakly developed muscle bounding ridges are present laterally (Fig. 9K). The cardinal process has become bilobed and elevated on a notothyrial platform. The dorsal valve median ridge is enlarged and the adductor scars are separated by weakly developed ridges divergent from the median ridge at 90°. The sockets of juvenile specimens are raised on secondary shell material and lack fulcral plates (Fig. 9N).

The same growth patterns observed in sub-adult *T. spedeni* continue into adults. In particular, adult specimens are almost equally biconvex, the ventral valve remaining slightly more strongly convex than the dorsal valve (Fig. 9G, H). Internally, the muscle fields of both valves have become more firmly impressed and the muscle bounding ridges are more strongly developed (Fig. 9E, F). Gerontic specimens appear very similar to adult specimens, but have more deeply impressed muscle scars and more strongly developed muscle-bounding ridges in both valves. The cardinal process of some gerontic specimens is trilobed.

Subfamily PROKOPIINAE Wright, 1965
Prokopia Havlíček, 1953

Type species. By original designation of Havlíček (1953: 6); *Prokopia bouskai* Havlíček, 1953; Pragian Dvorce-Prokop Limestone, Barrandov, Czech Republic.

Prokopia hillae (Chatterton, 1973)
Fig. 9J-R

Muriferella hillae sp. nov. Chatterton 1973: 28, pl. 3, figs 1–9, 11–15; pl. 35, figs 4, 5.
Prokopia hillae-Lenz & Johnson 1985a: 53, pl. 3, figs 1–12.

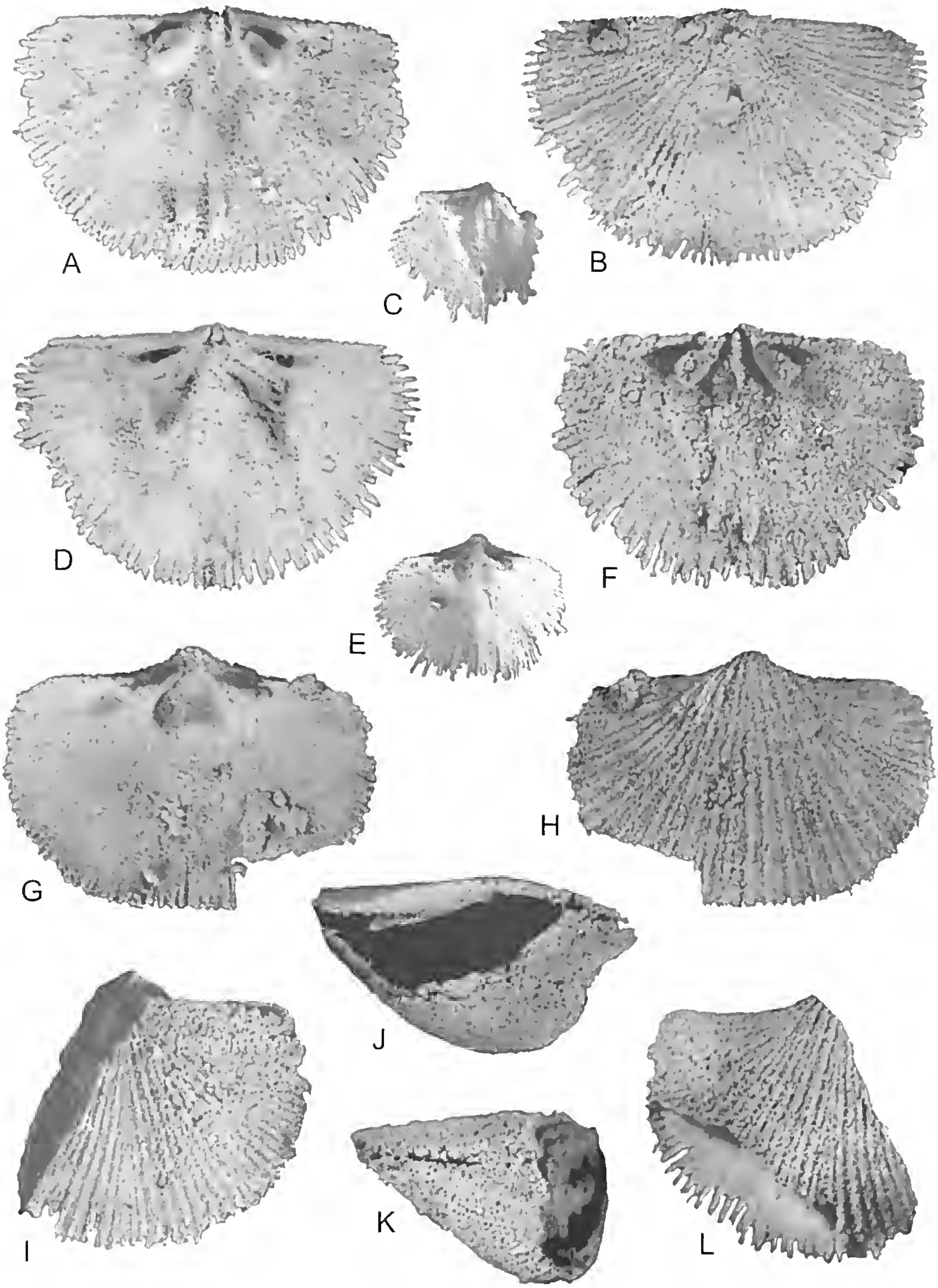
Material. Figured material: AM F117268 (Fig. 9J-L): dorsal valve from ROC 174.1; AM F117269 (Fig. 9M, N): ventral valve from McL 420dh; AM F117270 (Fig. 9O-R): articulated specimen from McL 420dh. Unfigured material: 65 ventral valves, 37 dorsal valves and 12 articulated specimens.

Description. See Chatterton (1973: 28).

Remarks. Following Lenz & Johnson (1985a), *M. hillae* is assigned here to *Prokopia* on the presence of a high triangular median septum in the dorsal valve. Talent et al. (2001), on the other hand, placed this species in synonymy with *M. punctata* (Talent, 1963). However, this synonymy cannot be supported as Johnson & Talent (1967: 44) stated that the median septum of *Muriferella* '....is not high and triangular. All of the specimens investigated show only a slight increase in height of the median septum in the anterior direction.' This statement holds true for all other described species of *Muriferella*.

Some of the specimens assigned to *P. hillae* from the Murrindal Limestone, as well as those described by Chatterton (1973: pl. 3, figs 2, 6, 9) from the Emsian Warroo Limestone Member of the Taemas Limestone at Taemas, differ from Havlíček's (1953) diagnosis for *Prokopia* in possessing fulcral plates (Fig. 9L). Whereas Lenz & Johnson (1985a) made no mention of fulcral plates in their description of *P. hillae* from the Pragian Garra Limestone at Wellington, their figured specimens (pl. 3, figs 1–12) appear to lack them. Although fulcral plates are more characteristic of *M. punctata* than *P. hillae*, they are an unreliable taxonomic feature as their presence varies with the age and size of the individual (Bancroft 1945; Brock pers. comm. 2000).

Fig. 11. *Bidigitus murrindalensis* gen. et sp. nov. All specimens x 8. A, B, holotype, dorsal valve interior and exterior, ROC 159, AM F117279. C, dorsal valve interior, ROC 174.1, AM F126354. D, dorsal valve interior, ROC 159, AM F117280. E, ventral valve interior, McL 420dh, AM F126355. F, dorsal valve interior, ROC 162, AM F117281. G, H, ventral valve interior and exterior, ROC 174.1, AM F117282. I-L, dorsal, lateral, posterior and ventral views of articulated specimen, ROC 162, AM F117283.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Therefore, the presence or absence of fulcral plates in these specimens cannot be considered sufficiently significant to rule out assignment of this species to *Prokopia*.

Subfamily RESSERELLINAE Walmsley & Boucot, 1971

Resserella Bancroft, 1928

Type species. By original designation of Bancroft (1928: 54); *Orthis canalis* Sowerby in Murchison, 1839; Early Silurian, Wenlock Shale, Woolhope Inlier, Herefordshire, Wales.

Resserella careyi Chatterton, 1973
Fig. 10A-G

Resserella careyi sp. nov. Chatterton 1973: 23, pl. 3, figs 10, 16–27.
Curranella careyi gen. et sp. nov. Chatterton 1973: pl. 35, figs 1–3.

Material. Figured material: AM F117271 (Fig. 10A, B) ventral valve from ROC 162; AM F117272 (Fig. 10C, D) dorsal valve from ROC 162; AM F126351 (Fig. 10E): ventral valve from ROC 159; AM F126352 (Fig. 10F): dorsal valve from ROC 159. Unfigured material: 601 ventral valves, 344 dorsal valves and 185 articulated specimens.

Description. See Chatterton (1973: 23).

Remarks. Chatterton (1973: 25) noted that *R. careyi* is unusual amongst *Resserella*, as diagnosed by Walmsley & Boucot (1971: 494), in possessing teeth and sockets that lack crenulations. However, the teeth of *R. springfieldensis* (Foerste, 1917) from the Wenlock Cedarville Dolomite of Ohio, were described by Walmsley & Boucot (1971: 513) as smooth. The ventral valve muscle field of *R. careyi* is largely confined to the delthyrial cavity and is chordate in juvenile to adult specimens (Fig. 10E-G), as seen in other *Resserella* species such as *R. basalis* (Dalman, 1828) and *R. elongata* (Dalman, 1828) (Walmsley & Boucot 1971). The ventral valve muscle field of gerontic specimens of *R. careyi* though is subtriangular to subpentagonal in outline (Fig. 10A). The *vascula media* of *R. careyi*, as illustrated by Chatterton (1973: pl. 3, figs 25, 27), are subparallel in both valves, a feature Walmsley & Boucot (1971) regard as diagnostic of *Resserella*. The primary difference between *R. careyi* and other *Resserella* is the symmetrical pattern of branching costellae in the medial region of the dorsal valve (Fig. 10D, F). In contrast, *Resserella* typically displays a pattern of asymmetrically bifurcating costellae in the medial region of the dorsal valve (Walmsley & Boucot 1971).

Some of the Murrindal specimens differ from Chatterton's (1973: 23) original description of *R. careyi* in possessing a short, but broad median ridge in the ventral valve located immediately anterior of the muscle field and disappearing by valve midlegth (Fig. 10A). *Resserella logansportensis* Walmsley & Boucot, 1971 from the Pridoli Kenneth Limestone of Indiana and *R. triangularis* (Maurer, 1889) from the Emsian of the Rhineland, both possess a median ridge, but it is much thinner in *R. triangularis* and does not increase in height anteriorly as in *R. logansportensis*. The dorsal valve median ridge of *R. careyi* also occasionally extends beyond the anterior margin of the diductor scars, a feature also occurring in *R. springfieldensis*. As these features tend only to occur in larger specimens, it is concluded they are characteristic of gerontic individuals.

Chatterton (1973: pl. 35, figs 1–3) figured several specimens under the name *Curranella careyi* gen. et sp. nov, despite referring to them as paratypes of *R. careyi* in the text. Strusz (1990: 9) determined this taxon is valid under ICZN Articles 13b and 68d, but as Chatterton (1973) obviously changed the generic placement of *C. careyi*, it can be considered a synonym of *R. careyi* (Strusz 1990).

Subfamily BIDIGITINAE subfam. nov.

Diagnosis. A dalmanellid with a dorsal valve median ridge bifurcating anteriorly into two finger-like projections, that may be raised unsupported above valve floor.

Type genus. By original designation herein; *Bidigitus* gen. nov.; Early Emsian of the Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Bidigitus gen. nov.

Type species. By original designation herein; *Bidigitus murrindalensis* sp. nov.; Emsian of the Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Etymology. L., *bi*, two; L., *digitus*, finger, in reference to the two finger-like projections of the bifurcating median ridge in the dorsal valve.

Type locality and horizon. ROC section (sample ROC 159), early Emsian (*perbonus* Zone), Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Diagnosis. As for subfamily by monotypy.

Bidigitus murrindalensis sp. nov.
Fig. 11A-L

Etymology. Named after the Murrindal Limestone from which this species was recovered.

Diagnosis. As for genus by monotypy.

Type material. Holotype: AM F117279 (Fig. 11A, B): holotype, dorsal valve from ROC 159. Figured paratypes: AM F126354 (Fig. 11C): dorsal valve from 174.1; AM F117280 (Fig. 11D): dorsal valve from ROC 159; AM F126355 (Fig. 11E): ventral valve from McL 420dh; AM F117281 (Fig. 11F): dorsal valve from ROC 162; AM F117282 (Fig. 11G, H): ventral valve from ROC 174.1; AM F117283 (Figs 11I-L): articulated specimen from ROC 162. Unfigured paratypes: 81 ventral valves, 33 dorsal valves and two articulated specimens.

Description. Planoconvex, subcircular to transversely suboval in outline. Width and length approximately equal. Greatest width occurring at, or slightly forward of, hinge line. Cardinal extremities rounded. Ventral valve with weak fold, but median portion more strongly convex than lateral slopes. Dorsal valve with weak, anteriorly widening, sulcus. Anterior commissure weakly unisulcate. Ornament finely parvicostellate.

Ventral valve interarea triangular, apsacline and incurved. Delthyrium broadly triangular, enclosing an angle of 90° that may be blocked apically by secondary shell material and laterally by narrow deltidial plates. Dorsal valve interarea low, elongately triangular and anacline to almost catacline. Interarea interrupted medially by a triangular notothyrium.

Ventral valve interior with deep delthyrial cavity. Non-crenulate, triangular teeth extend down to valve floor or supported by short, stout dental plates. Small, nonstriate crural fossettes impressed on sides of teeth. Shallow to deep lateral cavities present between teeth or dental plates and valve wall. Muscle field chordate, largely confined to delthyrial cavity, with gently arcuate anterior margin. Diductor and adductor muscle scars not well differentiated. Diductors appear to extend further forward than, but do not completely enclose, adductors. Adductor scars broader than diductor scars. Muscle field may be elevated slightly relative to valve floor. Inner surface smooth, apart from crenulated margins.

Dorsal valve interior with posteriorly bilobed cardinal process and myophore. Shaft of cardinal process joins narrow, posteriorly grooved, median ridge. Median ridge low, broad, dividing muscle field. Median ridge bifurcating slightly posterior of anterior margin of muscle field into two finger-like projections extending beyond anterior margin of muscle field, and may be raised, unsupported above valve floor. Brachiophores thickened, rod-like and diverge at 85°. Brachiophore plates continue forward as low muscle bounding ridges laterally, fading away anteriorly. Sockets excavated in valve floor and lacking fulcral plates. Muscle field subtriangular, narrowing anteriorly and not obviously divided into posterior and anterior pairs of adductor scars. Inner surface punctate with crenulated margins.

Measurements. Dimensions are shown in Fig. 12. Average ventral valve width 5.59 mm, length 4.32 mm. Average dorsal valve width 8.9 mm, length is 6.2 mm.

Remarks. *Bidigitus* is assigned to the new subfamily, Bidigitinae, within the Dalmanellidae based on its weakly ventribiconvex to planoconvex profile, chordate ventral valve muscle field that is largely

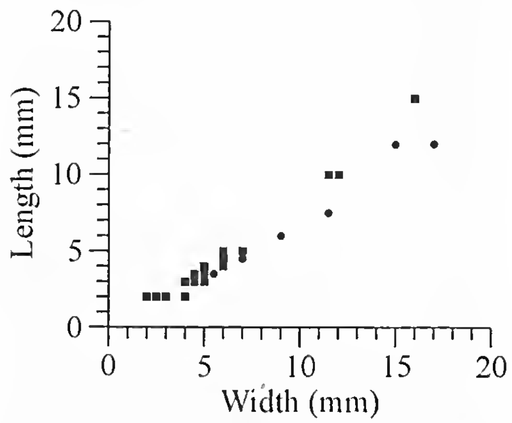


Fig. 12. Dimensions for *Bidigitus murrindalensis* gen. et sp. nov. Length vs width of ■ ventral (n = 28) and ● dorsal valves (n = 10).

confined to the delthyrial cavity and diductor scars that do not enclose the adductor scars (Fig. 11E). In the dorsal valve simple rod-like brachiophores are supported by brachiophore plates and fulcral plates are absent (Fig. 11A, C). *Bidigitus* is distinguished from all other dalmanellid subfamilies by a dorsal valve median ridge that bifurcates anteriorly into two finger-like projections, that in some specimens stand free of the valve floor (Fig. 11I).

The finger-like projections of the median ridge of *B. murrindalensis* probably functioned as accessory lophophore supports to the brachiophores. An analogous structure can be observed in the species of the acrotretid, *Acrotretella*, such as *A. goldapiensis* Biernat & Harper, 1999 and *A. triseptata* Mergl, 2001. In addition to the median septum, these species also possess lateral accessary septa, providing extra support for the lophophore.

Bidigitus murrindalensis has a stratigraphic range extending throughout the ROC section of the Murrindal Limestone, but only occurs in the lower sampled horizons of the McL section (Tables 1, 2). Talent (pers. comm. 2000) however, has indicated that *B. murrindalensis* also occurs in latest Pragian to early Emsian Buchan Caves Limestone.

Ontogeny. Neanic *B. murrindalensis* recovered are all incomplete. The shells are ventri-biconvex with a deep, broad sulcus in the dorsal valve, whereas the ventral valve is evenly convex. The triangular ventral valve interarea is steeply anacline and is flat or slightly curved. The delthyrium is blocked laterally by small deltidial plates, which may or may not join together posteriorly to block the apex of the delthyrium (Fig. 10F). The dorsal valve interarea is flat and anacline. Internally, the ventral valve possesses a deep delthyrial cavity to which the cordate to subtriangular muscle field is largely confined. The teeth are strongly developed, triangular in cross section and fused directly to the valve wall. Some specimens possess faintly impressed crural fossettes. Lateral cavities developed as shallow depressions only (Fig. 10F). The dorsal valve possesses long flattened brachiophores supported by variably developed brachiophore plates that continue forward as faint muscle bounding ridges. The cardinal process occurs as a simple, unlobed ridge, continuous with the broad, low median ridge, which bears a groove extending along its length. The two thin, finger-like bifurcations of the median ridge are raised, unsupported above the valve floor. The muscle-field is subtriangular and not obviously quadripartite. The triangular sockets, variably raised on secondary shell material, are covered posteriorly by the dorsal valve interarea (Fig. 10C).

Juvenile specimens of *B. murrindalensis* possess features intermediate between those of earlier and later growth stages. An apparent exception to this is the presence of a weakly developed fold, or even a keel, in the ventral valve of some specimens. Such a feature is not seen in other growth stages. In addition, punctae are clearly visible in both valves of juvenile specimens.

Sub-adult to adult specimens of *B. murrindalensis* are planoconvex, the dorsal valve sulcus having become indistinct (Fig. 10J, K). Internally, the muscle fields of both valves are more firmly impressed and the ventral valve muscle field is largely confined to the delthyrial cavity and has an elevated anterior margin. The teeth are strong, robust and supported in some specimens by short, stout dental plates with strongly impressed crural fossettes. Lateral cavities well developed and distinct (Fig. 11G). The dorsal valve muscle field is bounded by thicker ridges and is elevated above the valve floor. The cardinal process is bilobed in all specimens. The brachiophores are thickened and the sockets of all adult specimens are raised on secondary shell material. The groove on the median ridge is indistinct, particularly posteriorly. The bifurcating prongs of the median ridge are fused to the valve floor throughout their length in most specimens (Fig. 11A, D, F).

The only gerontic specimens recovered are two dorsal valves. These are both flat, with only the faintest trace of a sulcus. Internally, these specimens differ most notably from adult specimens in possessing a prominent bilobed to trilobed cardinal process that fills the notothyrium.

Family MYSTROPHORIDAE Schuchert & Cooper, 1931

Biernatium Havlíček, 1975

Type species. By original designation of Havlíček (1975: 234); *Skenidium fallax* Gürich, 1896; Givetian of the Celechovice na Hane (upper 'red' horizon) of Moravia.

Remarks. Biernat (1959) placed *B. fallax* in synonymy with *Kayserella lepida* (Schnur, 1853) as she considered the internal features of the dorsal valves identical. This assessment cannot be supported as the cruralium of *B. fallax* is long, narrow and

extends almost to the anterior margin (Havlíček 1977), whereas the cruralium of *Kayersella* Hall & Clarke, 1892 is restricted to the posterior portion of the valve (Biernat 1959). *Mystrophora* Kayser, 1871, unlike *Biernatium*, possesses a median ridge in the ventral valve (Havlíček 1977; Harper 2000). *Planicardinia* Savage, 1968 from the Lochkovian tongue of Garra Limestone at Manildra, in contrast to *Biernatium*, possesses a vertical, spoon-shaped cruralium. Members of the Protorthida possessing a cruralium, like *Skenidioides* Schuchert & Cooper, 1931, differ from *Biernatium* in possessing an open delthyrium, a free spondylium and are impunctate (Williams & Harper 2000).

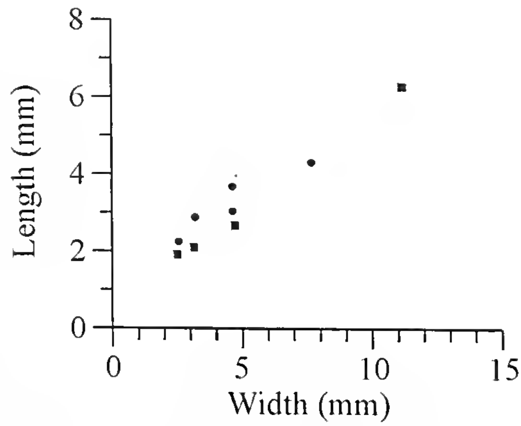


Fig. 13. Dimensions for *Biernatium catastum* sp. nov. Length vs width of ■ ventral (n = 4) and ● dorsal valves (n = 5).

Biernatium catastum sp. nov.
Fig. 10H-M

Etymology. L. *catasta*, stage, platform, scaffold; in reference to the diamond-shaped cruralium.

Diagnosis. Biernatium with an elongate, diamond-shaped cruralium in the dorsal valve.

Type material. Holotype: AM F117274 (Fig. 10H-J): dorsal valve from McL 520. Figured paratypes: AM F117273 (Fig. 10K): ventral valve from McL 520; AM F117275 (Fig. 10L, M): dorsal valve from McL 520. Unfigured paratypes: 12 ventral valves, 18 dorsal valves and one articulated specimen.

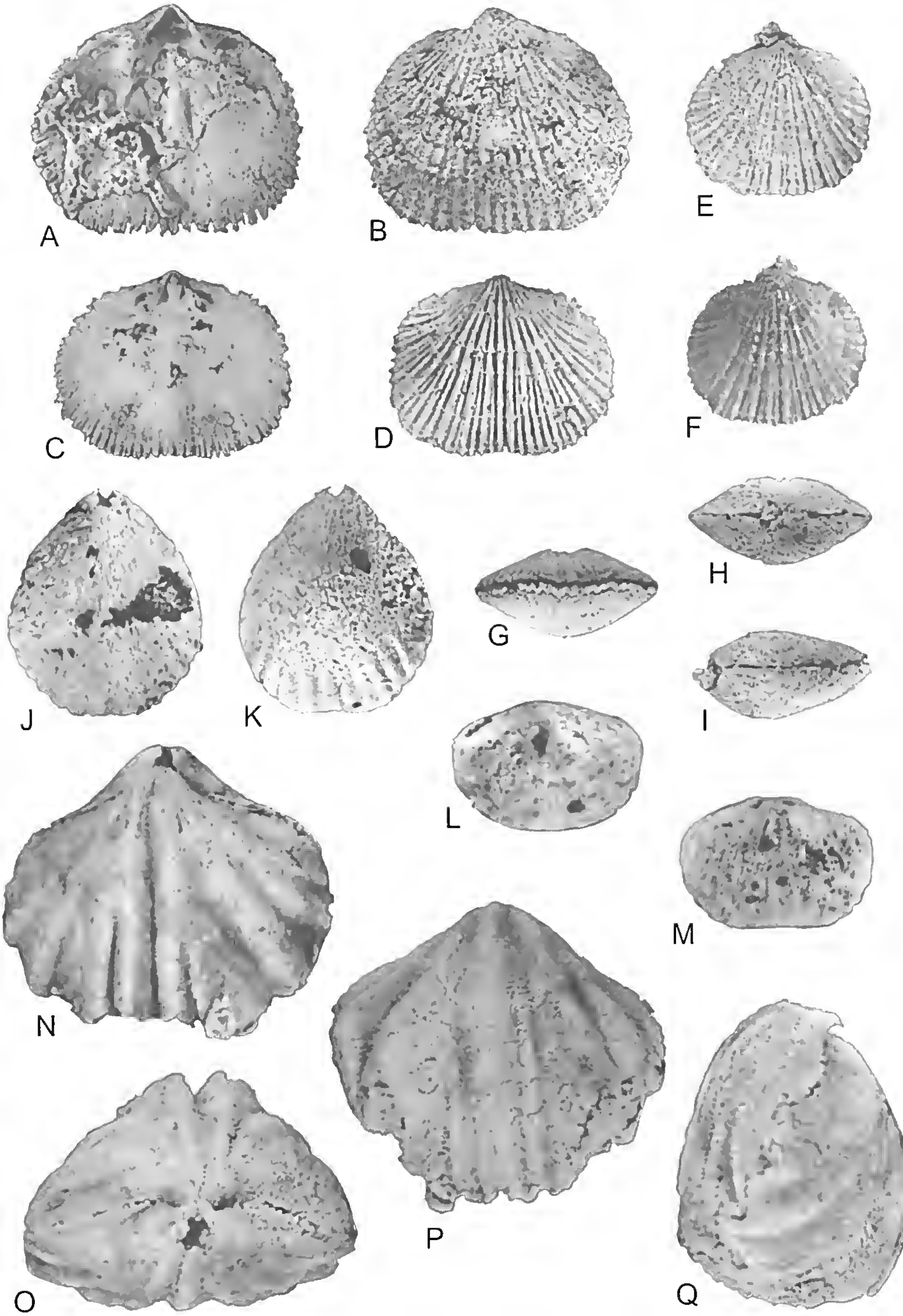
Type horizon and locality. McL section (sample McL 520), Emsian (*perbonus* Zone), Murrindal Limestone, Buchan Group, Buchan, Victoria, Australia.

Description. Ventribiconvex shells, transversely suboval in outline. Length tending to be slightly greater than width. Cardinal extremities rounded right angles. Maximum width occurring at, or slightly posterior of, midlength. Ventral valve subpyramidal, occasionally with a weakly developed fold. Dorsal valve weakly convex with well-developed sulcus extending from beak to anterior margin, becoming broader and deeper anteriorly. Base of sulcus angular. Anterior commissure unisulcate. Ornament of subangular costae and occasional growth lines.

Ventral valve interarea triangular, steeply apsacline to almost catacline and slightly curved. Delthyrium triangular, higher than wide, enclosing angle of 70°. Delthyrium restricted apically by minute plate and laterally by thin deltidial plates. Dorsal valve interarea triangular, wider than high, steeply anacline and flat. Notothyrium broadly triangular and blocked apically by cardinal process.

Ventral valve interior with deep delthyrial cavity. Teeth flat, triangular and supported by recessive, subparallel dental plates. Muscle field subtriangular and confined largely to posterior half of delthyrial cavity. Anterior margin of muscle field gently arcuate and raised above valve floor. Diductor scars slightly longer than adductor scars, but do not enclose adductors anteriorly. Adductor scars broader than diductors. Inner surface finely crenulate with a suggestion of punctation.

Dorsal valve interior with thickened, ridge-like cardinal process (bilobed in one specimen) with myophore and shaft continuous with median septum. Sockets shallow, raised above valve floor on secondary shell material, lacking fulcral plates. Interarea covers posterior portion of sockets. Median septum thin, triangular in side view, reaching maximum height close to anterior margin and ending at anterior margin. Brachiophores long, triangularly pointed and divergent at 110°. Thin brachiophore plates convergent onto median septum, forming a diamond-shaped cruralium extending at least to valve midlength. Cruralium deeply concave and attached to valve floor posteriorly, rising anteriorly at 30°, becoming shallower as its height increases. Cruralium divided into four fields by median septum and two low, rounded and indistinct ridges, convergent towards cardinal process. Inner surface punctate and marked, at least marginally, by fine crenulations.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Measurements. Dimensions are shown in Fig. 13. Average ventral valve width 5.44 mm, length 3.2 mm. Average dorsal valve width 4.96 mm, length 3.23 mm.

Remarks. *Biernatium catastum* differs from *B. fallax* from the Givetian shales of the Grzegorzowiee-Skaly section of the Holy Cross Mountains of Poland (Havlíček 1977), Givetian of the Celechovice na Hane (upper 'red' horizon) of Moravia (Fiehner & Havlíček 1978) and questionably from the Eifelian of Padaukpin (Northern Shan States), Burma (Havlíček 1975, 1977), primarily on features of the eruralium. The cruralium of *B. fallax* arises from widely divergent brachiophores situated subparallel to the hinge line, making the cruralium triangular in shape and much narrower anteriorly than the cruralium of *B. catastum*. The cruralium of *B. fallax* also possesses a weak undulation at its midpoint that, according to Havlíček (1977), resembles the quadripartite condition of the cruralium of *Mystrophora areola* (Quenstedt, 1871). *Biernatium catastum* lacks this feature (Fig. 10H, I, L). In addition, the outline of *B. fallax*, which is semi-oval or semicircular, differs from the transversely suboval outline of *B. catastum*.

The Murrindal specimens appear most closely related to *B. simplicior* (Barrande, 1879) from the Pragian Koneprusy Limestone of the Czech Republic (Havlíček 1977). Both possess a long cruralium, a high, triangular median septum and a delthyrium blocked laterally by thin deltidial plates and apically by a tiny plate (Fig. 10J). However, according to the diagnosis given by Havlíček (1977: 208), the cruralium of *B. simplicior*, like the cruralium of *B. fallax*, appears to be triangular in shape, suggesting that the brachiophores of *B. simplicior* are more widely divergent than those of *B. catastum*. Direct comparisons, however, are not possible as neither Barrande (1879) nor Havlíček (1977) illustrated the dorsal valve interior of *B. simplicior*.

Kayserella emanuelensis Veevers, 1959, from the Frasnian of the Fitzroy Basin of Western Australia, is reassigned herein to *Biernatium* following Havlíček (1977), on the basis that the cruralium extends almost to the anterior margin. However, the cruralium of *B. emanuelensis* differs markedly from other members of this genus in remaining narrow throughout its length and possessing undulating, rather than straight edges. In addition, the median septum of *B. emanuelensis* reaches its highest point around valve midlength, whereas in *B. catastum* this feature occurs closer to the anterior margin (Fig. 10I, L).

Family RHIPIDOMELLIDAE Schuchert, 1913
Subfamily RHIPIDOMELLINAE Schuchert, 1913

Aulacella Schuchert & Cooper, 1931

Type species. By original designation of Schuchert & Cooper (1931: 246); *Orthis eifliensis* Schnur, 1853; Eifelian of the 'Kalk' of the Eifel, Germany.

Aulacella philipi Chatterton, 1973
Fig. 14A-I

Aulacella philipi sp. nov. Chatterton 1973: 31, pl. 4, figs 13–20; pl. 5, figs 9–15; pl. 35, figs 10, 11.-Broek & Talent 1993: 233, fig. 10A-O.
Aulacella stoermeri sp. nov. Chatterton 1973: 34, pl. 4, figs 1–12; pl. 5, figs 1–8.

Material. Figured material: AM F117284 (Fig. 14A, B): ventral valve from McL 420dh; AM F117285 (Fig. 14C, D): dorsal valve from McL 420dh; AM F117286 (Fig. 14E-I): articulated specimen from ROC 165. Unfigured material: 56 ventral valves, 91 dorsal valves and eight articulated specimens.

Description. See Chatterton (1973: 31).

Remarks. Chatterton (1973) described two new species of *Aulacella*, *A. philipi* and *A. stoermeri* from the Emsian '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas. He differentiated between them on slight differences in the position of maximum width, length of the hinge line compared to maximum width, degree of flabellation of the diductor scars and the amount of scalloping of the lateral muscle bounding ridges in the muscle field of the ventral valve. However, Chatterton (1973: 34) and Broek & Talent (1993: 233) noted that considerable variation occurs in many features of *A. philipi*. Therefore, these differences

Fig. 14. A-I, *Aulacella philipi* Chatterton, 1973. All specimens x 3. A, B, ventral valve interior and exterior, McL 420dh, AM F117284. C, D, dorsal valve interior and exterior, McL 420dh, AM F117285. E-I, dorsal, ventral, anterior, posterior and lateral views of articulated specimen, ROC 165, AM F117286. J-M, *Eoglossinotoechia linki* Chatterton, 1973, ventral, dorsal, posterior and anterior views of articulated specimen, ROC 162, AM F117287, x7. N-Q, '*Pugnax*' *oepiki* Chatterton, 1973. N-Q, dorsal, posterior, ventral and lateral views of articulated specimen, McL 417, AFM117288, x 4.

are considered to fall within the range of intraspecific variation.

Chatterton (1973) and Brock & Talent (1993) believed *A. philipi* to be closely related to the type species, *A. eifliensis* from the Eifelian of Germany and Poland. Chatterton (1973) separated these two species on the basis that *A. philipi* has less rounded costellae and smaller brachiophore plates and teeth. However, given the considerable level of intraspecific variation displayed by *A. philipi*, Chatterton (1973: 34) stated that it was difficult to separate the two species on other characteristics. Brock & Talent (1993) believed these variations may not be significant at the species level and that *A. philipi* could be a junior synonym of *A. eifliensis*. However, comparisons between the two species are difficult due to the considerable level of intraspecific variation displayed.

Order RHYNCHONELLIDA Khun, 1949
Superfamily UNCINULOIDEA Rzhonsnitskaya, 1956
Family GLOSSINOTOECHIIDAE Havlíček, 1992

Eoglossinotoechia Havlíček, 1959a

Type species. By original designation of Havlíček (1959a: 81); *Eoglossinotoechia cacuminata* Havlíček, 1959a; late Lochkovian-Pragian of the Slivenec Limestone, Dvorce, Czech Republic.

Eoglossinotoechia linki Chatterton, 1973
Fig. 14J-M

Eoglossinotoechia linki sp. nov. Chatterton 1973: 120, pl. 31, figs 1–22, 27.-Xu 1987: 38, pl. 3, fig. 21.

Material. Figured material: AM F117287 (Fig. 14J-M): articulated specimen from ROC 162. Unfigured material: 14 articulated specimens.

Description. See Chatterton (1973: 120).

Remarks. The specimens assigned to *E. linki* from the Murrindal Limestone closely resemble those recovered by Chatterton (1973) from the Emsian '*Receptaculites*' Limestone Member at Taemas. However, as only articulated specimens have been recovered from the Murrindal Limestone, a comparison of internal features is not possible. The Murrindal specimens differ most notably though from those described by Chatterton (1973) in being smaller (Fig. 15), but only four of the specimens recovered were complete enough to obtain accurate dimensions. The Murrindal specimens also possess less pronounced costae, most likely related to their smaller size.

Eoglossinotoechia linki has also documented by Xu (1987) from the Pragian Daredong Formation of China. The single specimen figured by Xu (1987: pl. 3, fig. 21) has 21 plications developed along the anterior and lateral margins, and falls within the range of 20 to 28 plications established by Chatterton (1973) for mature specimens of *E. linki*. Like *E. linki* from the '*Receptaculites*' Limestone Member, those from the Daredong Formation are larger than the Murrindal specimens (Fig. 15).

Eoglossinotoechia linki differs from *E. cacuminata* from the Silurian and Lower Devonian of the Czech Republic (Havlíček 1959a), in possessing fewer and more prominent costae, a less convex ventral valve and a more obviously bilobate cardinal process. Other *Eoglossinotoechia* from the same area, such as *E. mystica* Havlíček, 1959a and *E. sylphidea* (Barrande, 1847), possess fewer and less well-developed costae than *E. linki*. None of the Devonian species of *Eoglossinotoechia* reported

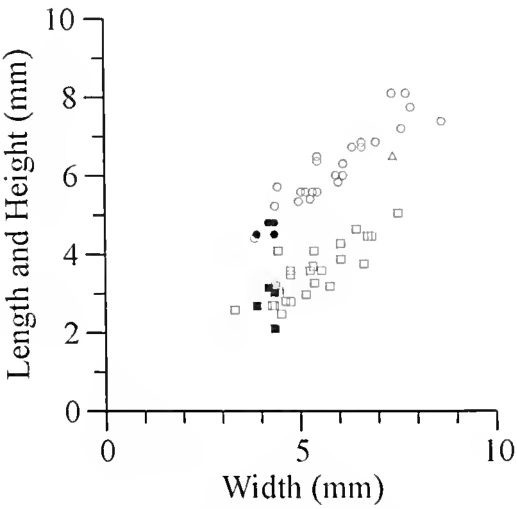


Fig. 15. Comparison of *Eoglossinotoechia linki* from the Emsian '*Receptaculites*' Limestone Member at Taemas (average width 16.7 mm; length 6.33 mm; height 4.07 mm) (Chatterton 1973: fig. 40), with *E. linki* from the Murrindal Limestone (average width 4.2 mm; length 4.65 mm; height 2.81 mm) and *E. linki* from the Pragian Daredong Formation of China (Xu 1987: pl. 3, fig. 21). Length vs width of ● Murrindal ($n = 4$), ○ Taemas ($n = 24$) and △ Daredong specimens ($n = 1$). Height vs width of ■ Murrindal ($n = 4$) and □ Taemas specimens ($n = 27$).

from Morocco by Drot (1964) appears closely related to *E. linki* (Chatterton 1973).

Chatterton's (1973) report of *E. linki* from Taemas was the first recorded occurrence of this genus in Australia. Since then, only one additional species of *Eoglossinotoechia* has been reported from Australia, *E. catombalensis* Lenz & Johnson, 1985b from the Pragian Garra Limestone at Wellington (Lenz & Johnson 1985b) and the Lochkovian Garra Limestone at Eurimbla (Brock 2003b) possesses fewer (12 to 18) and more rounded costae that are developed over the entire shell. The costae of *E. linki*, on the other hand, are flatter, more numerous (20 to 28) and only developed marginally. The ventral valve muscle field of *E. catombalensis* is subtriangular in outline, weakly impressed and divided by a prominent median ridge, whereas the ventral valve muscle field of *E. linki* is more variable in outline, strongly impressed and is not divided by a median ridge. In addition, the dorsal valve of *E. linki* contains a septalium, which is not developed in *E. catombalensis*.

Superfamily PUGNACOIDEA Rzhonsnitskaya, 1956
Family PUGNACIDAE Rzhonsnitskaya, 1956

Pugnax Hall & Clarke, 1893

Type species. By subsequent designation of ICZN Opinion 420 (1956: 134); *Terebratula acuminata* Sowerby, 1822; Visnean subzone D2, Dernyshire, Thorpe Cloud, England.

'Pugnax' oepiki Chatterton, 1973
Figs 14N-Q, 16A-I

'*Pugnax*' *oepiki* Chatterton 1973: 123, pl. 32, figs 25–41.

Material. Figured material: AM F117288 (Figs 14N-Q; 16I): articulated specimen from MeL 417; AM F117289 (Fig. 16A): articulated specimen from ROC 162; AM F117290 (Fig. 16B): articulated specimen from ROC 162; AM F117291 (Fig. 16C): articulated specimen from ROC 162; AM F117292 (Fig. 16D): articulated specimen from ROC 162; AM F117293 (Fig. 16E): articulated specimen from ROC 162; AM F117294 (Fig. 16F): articulated specimen from ROC 162; AM F117295 (Fig. 16G): articulated specimen from ROC 162; AM F117296 (Fig. 16H): articulated specimen from ROC 165; AM F117288 (Fig. 16I): articulated specimen from MeL 417. Unfigured material: 11 ventral valve fragments, two dorsal valve fragments and 36 articulated specimens.

Description. See Chatterton (1973: 123).

Remarks. Chatterton (1973) questionably assigned this species to *Pugnax* on the basis of a few dorsal valve interiors showing that the crural bases are extended dorsally, fused with the valve floor, and do not converge towards a median septum to form a septalium. Chatterton (1973: 125) also noted this species possesses similarities with *Parapugnax*, such as a well-defined fold and sulcus and a ventral valve that is not flat or concave posteriorly. In addition, this species differs from most other pugnacids, including the type species, in possessing a thin, posteriorly perforated hinge plate that unites the crural bases (Chatterton 1973). This suite of characteristics led Talent et al. (2001) to propose that '*P.*' *oepiki* may represent a new genus of Pugnacidae, but additional dorsal valve interiors are required before a more positive generic identification is possible. None of the specimens recovered from the Murrindal Limestone show any internal structures.

Order SPIRIFERIDA Waagen, 1883

Remarks. The higher level classification used for the Spiriferida herein follows that of Carter et al. (1994).

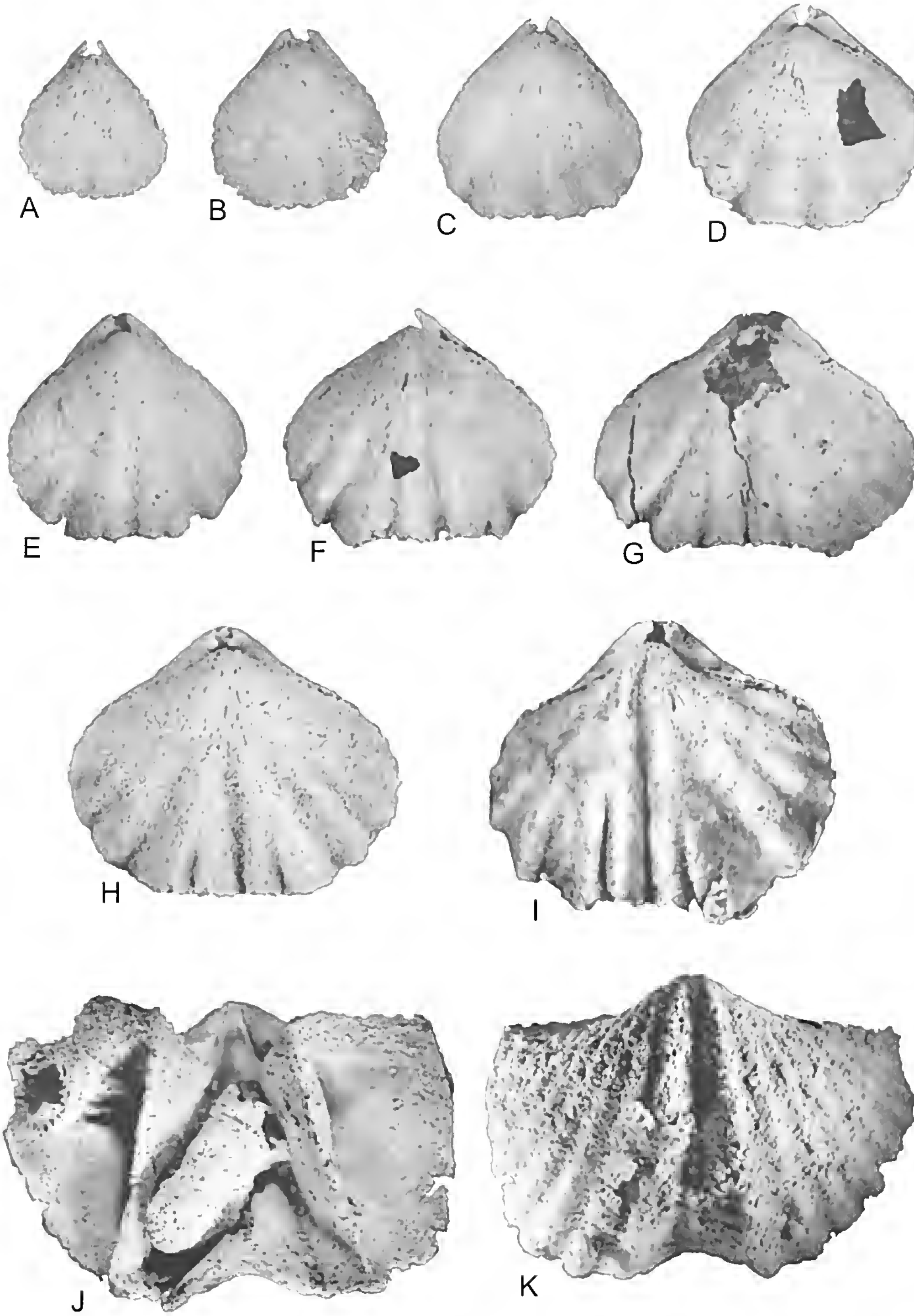
Suborder SPIRIFERACEA Waagen, 1883
Superfamily CYRTIOIDEA Frederiks, 1924
Family SPINELLIDAE Johnson, 1970
Subfamily SPINELLINAE Johnson, 1970

Spinella Talent, 1956a

Type species. By original designation of Talent (1956a: 21); *Spinella buchanensis buchanensis* Talent, 1956a; latest Pragian to early Emsian Buchan Caves Limestone, Buchan Group, Buchan, Victoria, Australia.

Spinella buchanensis buchanensis Talent, 1956a
Figs 16J, K, 17A, B

Spirifera laevicostata-McCoy 1876: pl. 35, figs 2–2b.
Spirifer yassensis-Chapman 1905: 16, pl. 5, figs 2, 3.-?Chapman 1914: 161, fig. 86E.
Spinella buchanensis sp. nov. Talent 1956a: 22, pl. 1, figs 1–5; pl. 2, figs 5–7.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?*Spinella*? sp. aff. *S. buchanensis*-Talent 1963: 85, pl. 53, figs 7–9.

Material. Figured material: AM F117297 (Fig. 16J, K): ventral valve from ROC 162; AM F117298 (Fig. 17A, B): dorsal valve from ROC 159. Unfigured material: 24 ventral valves, three dorsal valves and one articulated specimen.

Description. See Talent (1956a: 22).

Remarks. Talent (1956a) divided *S. buchanensis* into three new subspecies, *S. b. buchanensis*, *S. b. scissura* and *S. b. philipi* that differ primarily in the number of plications and in the arrangement of spine bases. The Murrindal specimens are conspecific with *S. b. buchanensis*, possessing lateral slopes with 11 to 14 simple plications. No spine bases were observed. In comparison, *S. b. philipi* is more obese, has lateral slopes bearing 13 to 18 simple plications and has a more strongly incurved ventral valve beak. *Spinella buchanensis scissura* is distinguished by lateral slopes with only 10 to 11 plications and by the plications flanking the sinus bearing a median groove (Talent 1956a). In addition, *S. b. buchanensis* is present not only throughout the Buchan Caves Limestone, but also extends up into the overlying Taravale Formation. The other two subspecies have relatively restricted stratigraphic ranges, being confined to the uppermost parts of the Buchan Caves Limestone (Talent 1956a).

Spinella maga Talent, 1956a, also from the Buchan Caves Limestone, possesses a greater number of plications (lateral slopes bear 18 to 20 plications), a more strongly incurved ventral valve beak and a granular surface ornament compared to *S. b. buchanensis*. *Spinella yassensis* (de Koninck, 1876), from Taemas (Chatterton 1973) and the Emsian Lick Hole Formation at Ravine (Strusz et al. 1970), is distinguishable by its smaller size, more elongate shell, higher fold, greater number of plications and a microornament of more elongate spine bases. *Spinella pittmani* (Dun, 1904), from the Emsian Gleninga Formation of the Yarra Yarra Creek Group and the late Pragian to early Emsian Troffs Formation (Dun 1904; Sherwin 1995; Földvary 2000), is similar in size to *S. b. buchanensis*. However, *S. b. buchanensis* is more transverse and has a more rounded sulcus (Sherwin 1995).

Spinella talenti Johnson, 1970a, from the Lower Devonian of Lone Mountain, Nevada, differs primarily in possessing a microornament of radial striae and tends to have flatter plications, but, as noted by both Talent (1956a: 27) and Johnson (1970a: 205), some specimens of *S. b. buchanensis* also have relatively flat plications. Perry (1984) questionably referred a dorsal valve fragment from the Pragian beds of the Delorme Formation to *Spinella*, which he described as being internally very similar to *S. talenti*.

Spinella incerta (Fuchs in Spriestersback & Fuchs, 1909), described by Vandercammen (1963) from the early Emsian of Belgium, appears markedly different from *S. b. buchanensis*. It possesses more numerous and finer plications and a sulcus lacking any costae. The microornament of *S. incerta* also differs in consisting of subcylindrical spine bases.

Spinella yassensis (de Koninck, 1876)
Fig. 17C-G

Spirifer yassensis de Koninck 1876: 104, pl. 3, fig. 6–6b.-de Koninck 1898: 83, pl. 3, fig. 6–6b.-Sussmilch 1914: fig. 23, 6–6b.-Sussmilch 1922: fig. 23, 6–6b.

Spirifer latisinuatus de Koninck 1876: 105, pl. 3, fig. 7–7b.-de Koninck 1898: 84, pl. 3, fig. 7–7b.

Spinella yassensis yassensis-Strusz, Chatterton & Flood 1970: 176, pl. 7, figs 1–14; pl. 8, figs 1–3, 7, 9–10; pl. 9, fig. 16.

Spinella yassensis ravinia n. subsp. Flood (in Strusz, Chatterton & Flood 1970): 179, pl. 9, figs 1–14, 17.

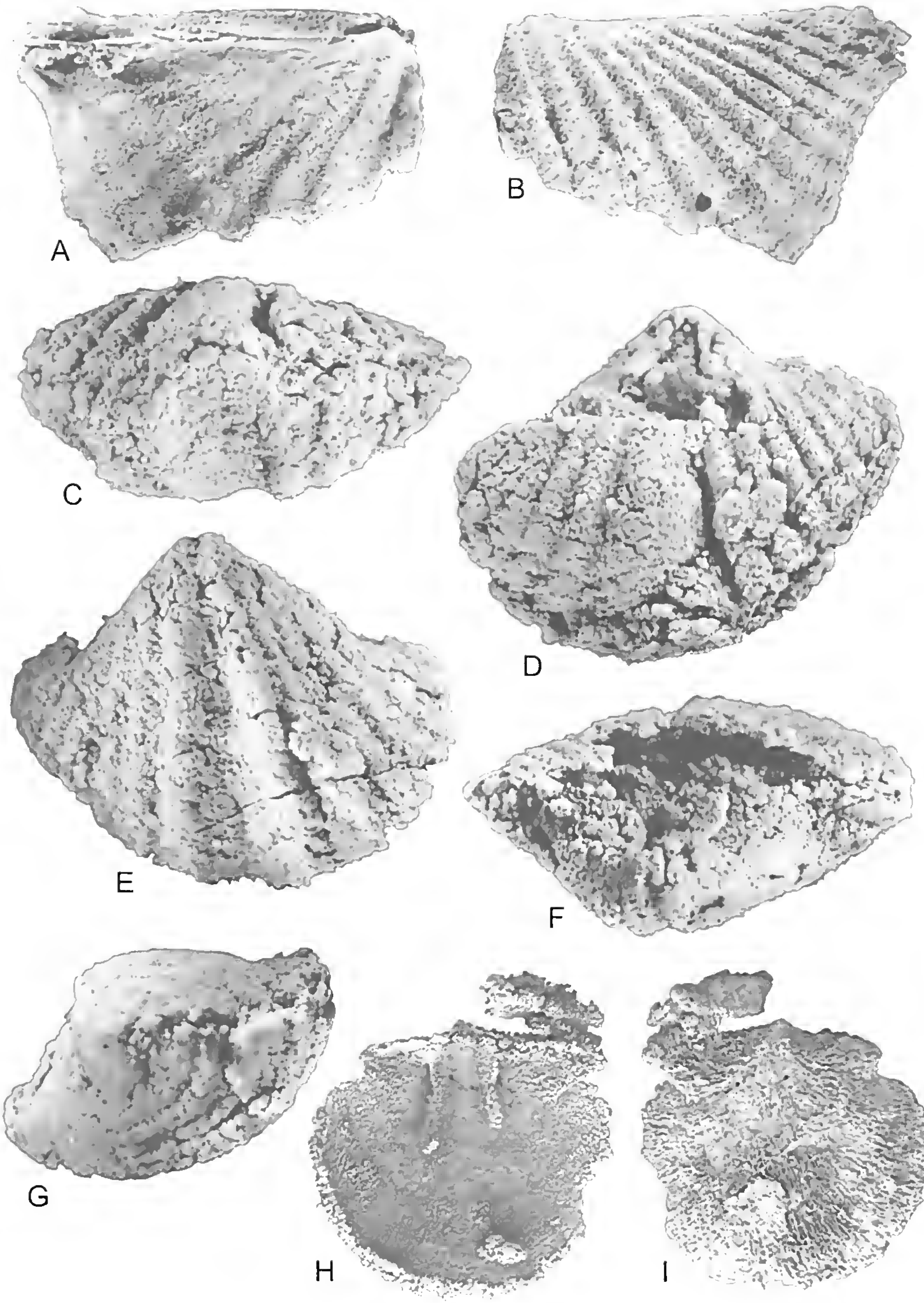
Spinella yassensis, n. subsp? Strusz, Chatterton & Flood 1970: 181, pl. 8, figs 4–6, 8.

Spinella yassensis-Chatterton 1973: 105, pl. 26, figs 1–13; pl. 30, figs 16–20.

Material. Figured material: AM F117299 (Fig. 17C-G): articulated specimen from ROC 165. Unfigured material: one ventral valve.

Remarks. Flood (in Strusz et al. 1970) erected the new subspecies, *S. y. ravinia*, which was defined as having a significantly shallower shell with a narrower and flatter fold and a slightly higher number of plications than *S. y. yassensis*. Following Talent et

Fig. 16. A-I, '*Pugnax*' *oepiki* Chatterton, 1973. All specimens x 4. All dorsal views of articulated specimens. A-G, ROC 162, AM Fs117289-117295. H, ROC 165, AM F117296. I, McL 417, AM F117288. J, K, *Spinella buchanensis buchanensis* Talent, 1956a, ventral valve interior and exterior, ROC 162, AM F117297, x 3.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al. (2001), however, these differences are not considered great enough to warrant their separation from *S. y. yassensis*.

Strusz et al. (1970) also documented *Spinella yassensis* n. subsp? from the base of the Emsian '*Receptaculites*' Limestone Member at Taemas. It was described as being slightly larger, having a greater variability in shape and the curvature of the ventral valve interarea being less pronounced than *S. y. yassensis*. Statistical comparisons showed significant differences between *S. yassensis* n. subsp? and *S. y. yassensis* in terms of shape and relative width of the fold. However, as pointed out by Strusz *et al.* (1970: 181), only a handful of specimens were available for study and therefore any differences must be considered inconclusive. Until additional material is obtained designation of the Taemas form of *S. yassensis* as a new subspecies appears unwarranted.

Spinella yassensis differs from *S. buchanensis* in being smaller, more elongate, possessing a higher fold, a greater number of plications in some larger specimens and a microornament consisting of more elongate spine bases. *Spinella maga* possesses significantly more plications and growth lamellae that are only occasionally developed. *Spinella yassensis* appears very similar to *S. pittmani*, but is smaller and some have a ventral valve muscle field that is radially, rather than longitudinally, striate (Sherwin 1995).

Superfamily AMBOCOELIOIDEA George, 1931
Family AMBOCOELIIDAE George, 1931
Subfamily RHYNCHOSPIRIFERINAE
Paulus, 1957

Ambocoelia Hall, 1860

Type species. By original designation of Hall (1860: 71); *Orthis umbonata* Conrad, 1842; Middle Devonian Hamilton Group, New York, America.

Ambocoelia sp. aff. **A. runnegari**
(Chatterton, 1973)
Figs 17H, I, 18A-C

aff. *Ambothyris runnegari* sp. nov. Chatterton 1973: 99, pl. 19, figs 1–14.

Material. Figured material: AM F117300 (Fig. 17H, I): dorsal valve from MeL 520; AM F117301 (Fig. 18A, B): ventral valve from MeL 520; AM F117302 (Fig 18C): articulated specimen from MeL 520. Unfigured material: 15 ventral valves, 12 dorsal valves and three articulated specimens.

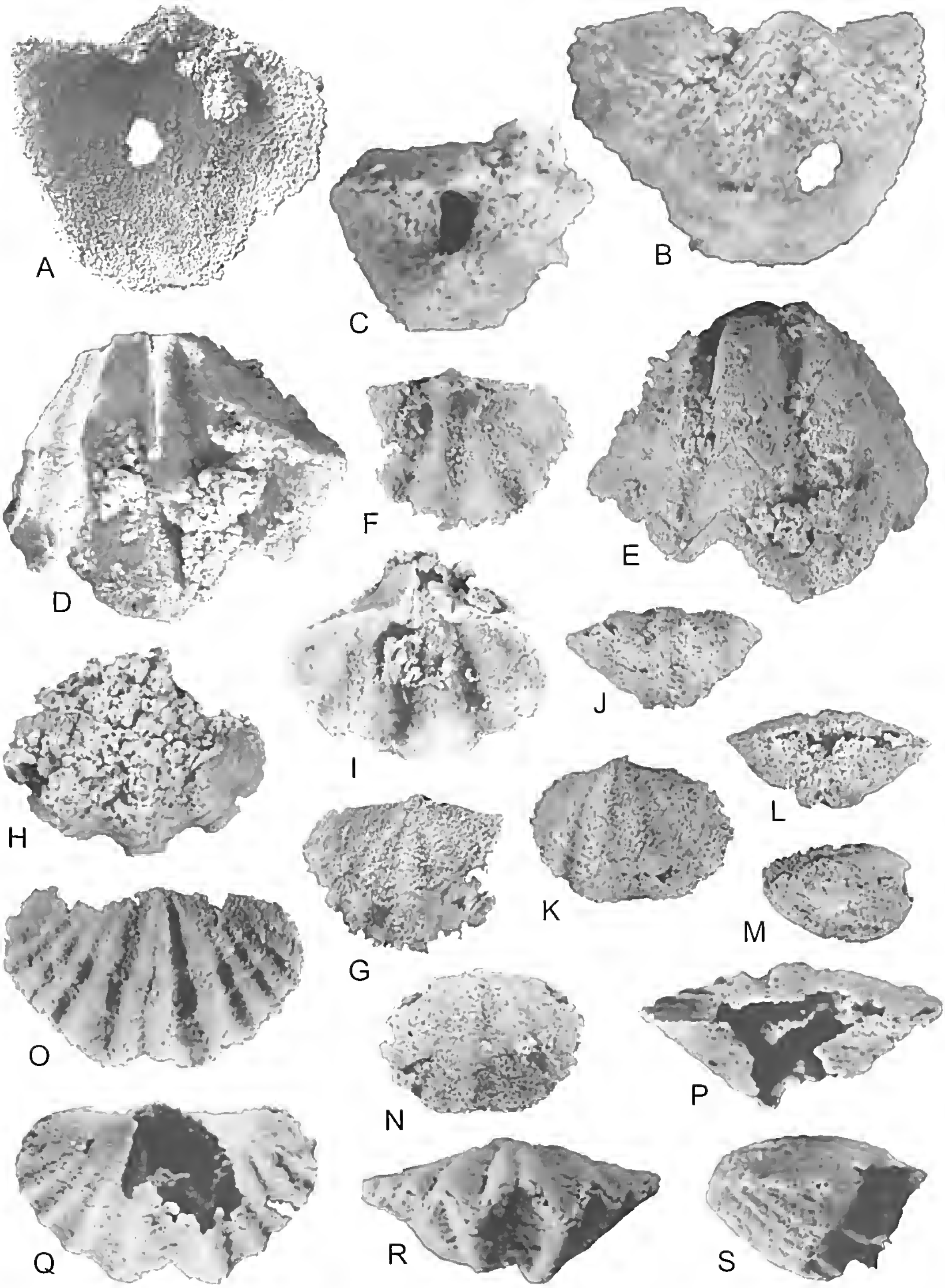
Description. See Chatterton (1973: 99).

Remarks. Chatterton (1973) assigned this species from the Emsian '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas to *Ambothyris* George, 1931 as it closely matched Havlíček's (1959b: 176) diagnosis for *Ambothyris*, only differing in possessing a rod-like plate in the apex of the delthyrium and the crural plates are not united to form a cruralium. Examination of Chatterton's (1973: pl. 19, figs 13, 14) figured material however indicates that crural plates are lacking in *A. runnegari*. As in the Murrindal specimens, the crura appear to be supported by crural bases only, which extend forward for about one third of the shell length (Fig. 17H). Following Carter et al. (1994), this species is therefore reassigned to *Ambocoelia*.

Although closely resembling *A. runnegari* in terms of profile, outline and ornament, the Murrindal specimens differ from Chatterton's (1973) material in possessing more variably developed dorsal and ventral valve sulci and lack the rod-like plate in the apex of the delthyrium (Fig. 18B, C). Only one specimen shows any trace of median ridge in the ventral valve (Fig. 18B). However, as few of the Murrindal specimens are free from secondary infilling, it is not possible to determine the presence of absence of a median ridge in the ventral valve. Comparison of microornament is not possible as none has been preserved in the Murrindal specimens. Alternatively, the Murrindal specimens may represent a new species closely related to *A. runnegari*.

Suborder DELTHYRIDINA Ivanova, 1972
Superfamily DELTHYRIDOIDEA Philips, 1841
Family DELTHYRIDIDAE Phillips, 1841
Subfamily DELTHYRIDINAE Phillips, 1841

Fig. 17. A, B, *Spinella buchanensis buchanensis* Talent, 1956a, dorsal valve interior and exterior, ROC 159, AM F117298, x 3. C-G, *Spinella yassensis* (de Koninck, 1876), anterior, dorsal, ventral, posterior and lateral views of articulated specimen, ROC 165, AM F117299, x 7. H, I, *Ambocoelia* sp. cf. *A. runnegari* (Chatterton, 1973), dorsal valve interior and exterior, MeL 520, AM F117300, x 20.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Delthyris Dalman, 1828

Type species. By original designation of Dalman (1828: 120); *Delthyris elevata* Dalman, 1828; Silurian of Gotland.

Delthyris? sp.
Fig. 18D, E

Material. Figured material: AM F117303 (Fig. 18D): ventral valve from McL 520. Unfigured material: six ventral valves.

Remarks. The plications of these specimens range from low and rounded to high and subangular, with well-developed growth lines (Fig. 18E). Internally, well-developed dental plates are present in at least one specimen and muscle scar impressions are lacking. These features, and their variability, are all reminiscent of *Cyrtina wellingtonensis* Dun, 1904, which has also been recovered from the Murrindal Limestone. However, these specimens have been tentatively assigned to *Delthyris* on the presence of a median septum in the ventral valve that terminates abruptly around valve midlength (Fig. 18D). In two specimens, the median septum appears to have a serrated anterior margin. These features suggest the affinities of this species lies with *Delthyris hudsoni* Chatterton, 1973, from the Emsian '*Receptaculties*' and Warroo Limestone Members of the Taemas Limestone at Taemas. Additional material is required for a more positive identification.

Subfamily HOWELLELLINAE Johnson & Hou (in Carter, Johnson, Gourvennec & Hou, 1994)

Howellella (Howellella) Kozlowski, 1946

Type species. By original designation of Kozlowski (1946: 295); *Delthyris elegans* Muir-Wood, 1925; Middle Silurian of Anglie.

Howellella (Howellella) textilis Talent, 1963
Fig. 18E-M

Howellella textilis n. sp. Talent 1963: 81, pl. 50, figs 1–43.
Howellella cf. *textilis*-Johnson 1970a: 186, pl. 55, figs 1–19.-Chatterton 1973: 106, pl. 27, figs 1–19.-Lenz & Johnson 1985b: 89, pl. 12, figs 10–22.
Howellella (*Howellella*) *textilis*-Brock 2003b: 81, pl. 11, figs 11–16.

Material. Figured material: AM F117304 (Fig. 18E, F): ventral valve from McL 420dh; AM F117305 (Fig. 18G, H): dorsal valve from McL 420dh; AM F117306 (Fig. 18I-M): articulated specimen from McL 420dh. Unfigured material: 62 ventral valves, 37 dorsal valves and 21 articulated specimens.

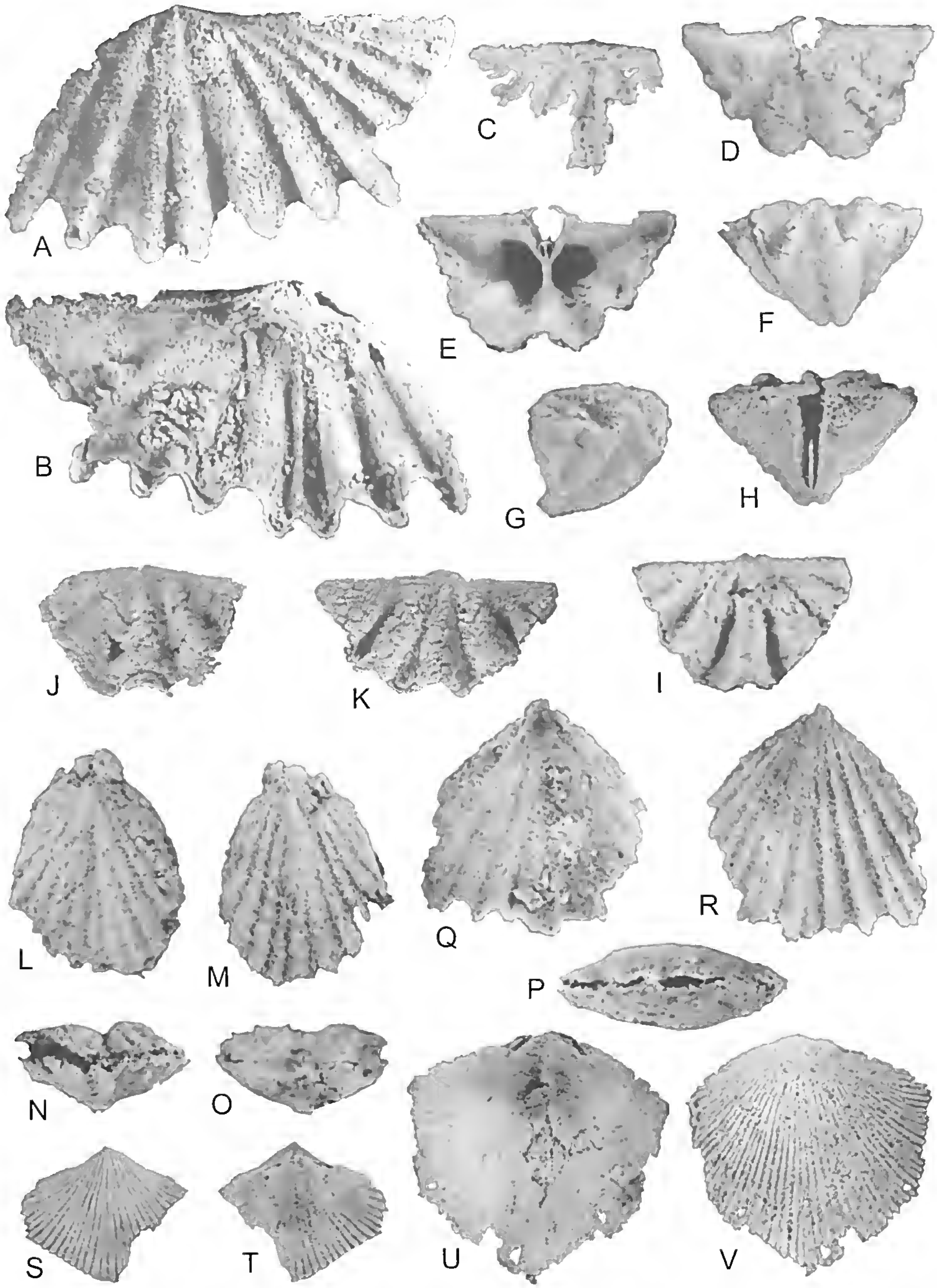
Description. See Talent (1963: 81).

Remarks. Most of the specimens recovered from the Murrindal Limestone closely resemble *H.* (*H.*) *textilis* from the late Pragian Lower Kilgower Member of the Tabberabbera Formation, differing only in some cases by possessing a greater number of plications and being slightly larger. However, these forms grade into forms identical to those described by Talent (1963).

Several species of *Howellella* have been reported from the Early Devonian Garra Limestone of New South Wales (Savage 1969; Lenz & Johnson 1985b; Farrell 1992; Brock 2003b). Of these, *H.* (*H.*) *textilis* appears most closely related to *H. mucula australis* Savage, 1969, but differs in possessing more plications, a stronger fold and sulcus and by being more transverse (Chatterton 1973). *Howellella talenti* Farrell, 1992 differs in possessing less prominent growth lamellae, lacking a myophragm in the ventral valve and crural plates that are convergent posteriorly and dorsally (Farrell 1992).

Mawson & Talent (1999) described four species of *Howellella, H. placoeotextilis, H. alatextilis, H. legirupa* and *H.* sp. from the Lochkovian Windellama Limestone of New South Wales. Both *H. placoeotextilis* and *H. alatextilis* appear to be closely related to *H.* (*H.*) *textilis*, but are distinguishable by differences in the ornament, with *H.* (*H.*) *textilis* having much narrower plications than the former and fewer plications than the latter. *Howellella alatextilis* also differs by being strongly alate (Mawson

Fig. 18. A-C, *Ambocoelia* sp. cf. *A. runnegari* (Chatterton, 1973). All specimens x 20. A, B, ventral valve interior and exterior, McL 520, AM F117301. C, posterior view of articulated specimen, McL 520, AM F117302. D, E, *Delthyris*? sp., ventral valve interior and exterior, McL 520, AM F117303, x3. E-M, *Howellella* (*Howellella*) *textilis* Talent, 1963. All specimens x 7. F, G, dorsal valve interior and exterior, McL 420dh, AM F117305. H, I, ventral valve interior and exterior, McL 420dh, AM F117304. J-N, anterior, ventral, posterior, lateral and dorsal views of articulated specimen, McL 420dh, AM F117306. O-S, *Howittia howitti* (Chapman, 1905), posterior, ventral, anterior and lateral views of articulated specimen, ROC 159, AM F117307, x7.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& Talent 1999). Whereas *H. legirupa* has a similar number and type of plications as *H. textilis*, it differs internally by possessing significantly larger dental plates as pointed out by Sherwin (1995).

Howittia Talent, 1956a

Type species. By original designation of Talent (1956a: 34); *Spirifer howitti* Chapman, 1905; latest Pragian to early Emsian of the Buchan Caves Limestone, Bindi, Victoria, Australia.

Howittia howitti (Chapman, 1905)
Figs 18N-R, 19A, B

Spirifer howitti sp. nov. Chapman 1905: 18, pl. 5, figs 4–6.
Howittia howitti-Talent 1956a: 34, pl. 2, figs 13–17.-Chatterton 1973: 112, pl. 24, figs 1–20.
Howittia cf. *H. howitti*-Lenz & Johnson 1985b: 90, pl. 14, figs 14–21.

Material. Figured material: AM F117307 (Fig. 18N-R): articulated specimen from ROC 159; AM F117308 (Fig. 19A, B): dorsal valve from ROC 159. Unfigured material: 10 ventral valves and three dorsal valves.

Description. See Chapman (1905: 18), Talent (1956a: 34) and Chatterton (1973: 112).

Remarks. These specimens can be readily assigned to *H. howitti* on the basis of the medial plication of the dorsal valve bearing a distinct groove, a feature Chapman (1905: 18) described as being one of the chief characteristics of *H. howitti*. *Howittia howitti* is very similar to *H. multiplicata* (de Koninck, 1876) from the Emsian limestones at Taemas (de Koninck 1876; Chatterton 1973) and the Lick Hole Formation at Ravine (Strusz et al. 1970), in terms of outline, microornament, delthyria, lateral plates and the subdivided fold and sulcus. However, they differ in that *H. multiplicata* has more plications, the fold of a mature dorsal valve is subdivided by at least five furrows and that the plications next to the fold and sulcus of *H. multiplicata* are usually subdivided near the umbo. Internally, *H. multiplicata* has shorter crural plates (Chatterton 1973).

Howittia haideri Soja, 1988, from the Emsian of Kasaan Island, southeastern Alaska, differs from *H. howitti* in being smaller, having fewer plications and with three plications consistently on the fold and two in the sulcus. Internally, the two species are virtually identical, but *H. haideri* has much thicker dental plates. An unnamed species of *Howittia* described by Perry (1984), from Emsian strata of the Delorme Formation of Canada, differs in possessing less prominent ventral valve adminicula and fewer plications. A second unnamed species of *Howittia*, described by Johnson (1971) from the Emsian of the Sulphur Spring Range of central Nevada, possesses fewer and stronger plications. In addition, the plication on the sulcus is much larger than in *H. howitti* (Johnson 1971).

Numerous species of *Howittia* have also been described from China, many of which occur in the early Emsian Nanning-Liujing district of central Guangxi in southern China (Wang & Rong 1986). They consistently differ from *H. howitti* in possessing fewer plications, up to eight at most. In addition, most species also possess more plications in the fold and grooves in the sulcus than *H. howitti*, and lack growth lamellae developed over the entire shell.

Order SPIRIFERINIDA Ivanova, 1972

Remarks. The higher level classification used for the Spiriferinida herein follows that of Carter et al. (1994).

Suborder CYRTINIDINA Carter & Johnson (in Carter, Johnson, Gourvennec & Hou 1994)
Superfamily CYRTINOIDEA Frederiks, 1911
Family CYRTININAE Frederiks, 1911

Cyrtina Davidson, 1858a

Type species. By subsequent designation of Hall & Clarke (1894: 44); *Calceola heteroclita* Defrance, 1824; Middle Devonian of western Europe.

Fig. 19. A, B, *Howittia howitti* (Chapman, 1905), dorsal valve exterior and interior, ROC 159, AM F117308, x 7. C-K, *Cyrtina wellingtonensis* Dun, 1904. All specimens x 5. C, dorsal valve interior, McL 420dh, AM F117310. D, E, ventral valve exterior and interior, McL 420dh, AM F117309. F-I, anterior, lateral, posterior and dorsal views of articulated specimen, ROC 162, AM F117311. J, dorsal valve exterior, McL 420dh, AM F126356. K, dorsal view of articulated specimen, ROC 165, AM F126357. L-R, *Coelospira dayi* Chatterton, 1973. All specimens x 7. L-P, dorsal, ventral, anterior, posterior and lateral views of articulated specimen, McL 497, AM F117312. Q, R, ventral valve interior and exterior, McL 497, AM F117313. S-V, *Variatrypa* (*Variatrypa*) *erectirostris* (Mitchell & Dun, 1920). All specimens x 2. S, T, ventral valve exterior and interior, McL 417, AM F117314. U, V, dorsal valve interior and exterior, ROC 162, AM F117315.

Cyrtina wellingtonensis Dun, 1904
Fig. 19C-K

Cyrtina wellingtonensis sp. nov. Dun 1904: 319, pl. 61, fig. 2–2e.-Broek 2003b: 85, pl. 9, figs 15–19; pl. 10, figs 1–4.
Cyrtina aff. *C. wellingtonensis*-Chatterton 1973: 101, pl. 23, figs 1–25.
?*Cyrtina* sp. 1 Lenz & Johnson 1985b: 87, pl. 11, figs 10–13.
Cyrtina sp. 2 Lenz & Johnson 1985b: 88, pl. 11, figs 14–17, 22.
?*Cyrtina* sp. 3 Lenz & Johnson 1985b: 88, pl. 11, figs 18–20, 22–25, 29.
Cyrtina sp. Broek & Talent 1993: 244, fig. 15A-E.

Material. Figured material: AM F117309 (Fig. 19D, E): ventral valve from MeL 420dh; AM F117310 (Fig 19C): dorsal valve from MeL 420dh; AM F117311 (Fig. 19F-I): articulated specimen from ROC 162; AM F126356 (Fig. 19J): dorsal valve from MeL 420dh; AM F126357 (Fig. 19K): articulated specimen from ROC 165. Unfigured material: 98 ventral valves, 70 dorsal valves and 157 articulated specimens.

Description. See Dun (1904: 319) and Chatterton (1973: 101).

Remarks. *Cyrtina* is a cosmopolitan genus that exhibits a high degree of intraspecific variation, leading to great difficulties in distinguishing between species, not only within each collection, but also between collections. Kozlowski (1929), Chatterton (1973), Lenz (1977b), Perry (1984), Lenz & Johnson (1985b), Farrell (1992) and Broek (2003b) have all commented on these difficulties. This variation is so great that Lenz & Johnson (1985b) merely divided their specimens of *Cyrtina* from the Pragian Garra Limestone at Wellington into three unnamed species. Perry (1984) did not even attempt to identify individual species, claiming that only through the statistical analysis of large collections could individual species be accurately identified. Such a study has yet to be undertaken.

The specimens assigned to *Cyrtina* from the Murrindal Limestone have proved no exception to this rule. Like most *Cyrtina*, the interareas of the Murrindal specimens range from flat to strongly curved (Fig. 19D, E, G, H, I, K); the plications are weakly to strongly developed and rounded to angular (Fig. 19D, F, G, I, J, K); concentric growth lines are faint and subdued to strongly developed (Fig. 19E, G, I, J, K); the cardinal extremities are rounded to angular (Fig. 19E, I, J, K); and some beaks are slightly twisted. As observed by Farrell (1992), these differences may be environmental in origin, a result of growth in a crowded environment, producing distorted shell growth.

Size has been frequently used to compare specimens of *Cyrtina* from different collections and to distinguish between different species (eg. Savage 1969; Farrell 1992). However, this appears to be an unreliable method of discriminating between individual species of *Cyrtina* as the size of many established species appears very similar. Broek (2003b: 86) has also shown that size can vary greatly intraspecifically.

A comparison of size versus the number of plications on the ventral and dorsal valves appears to separate eastern Australian specimens of *Cyrtina* into several distinct groups (Fig. 20). This analysis groups the Murrindal specimens with *C. wellingtonensis* from the Garra Limestone at Wellington (Dun 1904), *Cyrtina* sp. 2 from the Garra Limestone at Wellington (Lenz & Johnson 1985b), *C. wellingtonensis* from the Garra Limestone at Eurimbla (Broek 2003b), *Cyrtina* aff. *C. wellingtonensis* from the Emsian '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone at Taemas (Chatterton 1973), and *Cyrtina* sp. from the Emsian Ukalunda Beds of Queensland (Broek & Talent 1993). The Murrindal specimens have therefore been assigned to *C. wellingtonensis*.

This analysis also allows the Murrindal specimens to be separated from *C. heteroclita*, *C. imbricata* Farrell, 1992 from the Garra Limestone of New South Wales (Savage 1969; Farrell 1992) and *C. praecedens* Kozlowski, 1929 from the Windellama Limestone in New South Wales (Mawson & Talent 1999) (Fig. 20).

Cyrtina sp. 2 and 3, described by Lenz & Johnson (1985b) from the Garra Limestone of New South Wales, plot slightly outside the range determined for *C. wellingtonensis* in this study (Fig 20). Analysis of additional material is required to determine if these species also belong to *C. wellingtonensis*.

Order ATRYPIDA Rzhonsnitskaya, 1960
Suborder ATRYPIDINA Moore, 1952
Superfamily ATRYPOIDEA Gill, 1871
Family ATRYPIDAE Gill, 1871
Subfamily ATRYPINAE Gill, 1871

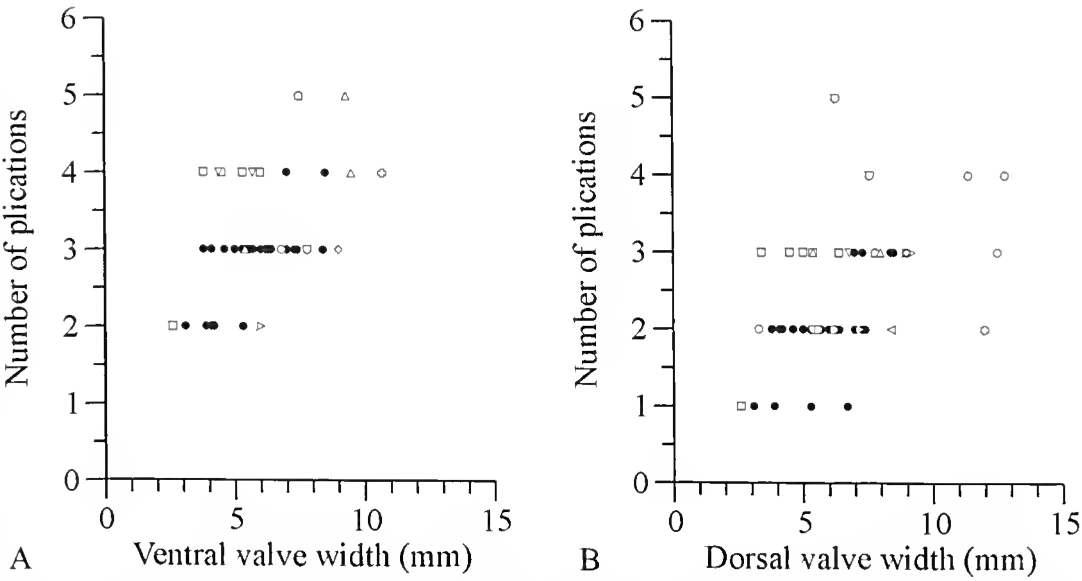


Fig. 20. Number of plications versus A, ventral valve width and B, dorsal valve width, for various Early Devonian species of *Cyrtina* from eastern Australia. ● *C. wellingtonensis* from the Murrindal Limestone, Buchan (A, n = 29; B, n = 29); ◇ *C. wellingtonensis* from the Garra Limestone, Wellington (A, n = 1; B, n = 1) (Dun 1904: pl. 61, fig. 2); ○ C. aff. *C. wellingtonensis* from the '*Receptaculites*' and Warroo Limestone Members of the Taemas Limestone, Taemas (A, n = 1; B, n = 5) (Chatterton 1973: pl. 23, figs 1–25). ◁ *Cyrtina* sp. 1 from the Garra Limestone, Wellington (A, n = 0; B, n = 1) (Lenz & Johnson 1985b: pl. 11, figs 10–13); *Cyrtina* sp. 2 from the Garra Limestone, Wellington (A, n = 0; B, n = 2) (Lenz & Johnson 1985b: pl. 11, figs 14–17, 21); ▷ *Cyrtina* sp. 3 from the Garra Limestone, Wellington (A, n = 1; B, n = 4) (Lenz & Johnson 1985b: pl. 11, figs 18–20, 22–25, 29); *Cyrtina* sp. from the Ukalunda Beds, northeast Queensland (A, n = 1; B, n = 1) (Brock & Talent 1993: fig. 15A-E); △ *C. wellingtonensis* from the Garra Limestone, Eurimbla (A, n = 3; B, n = 2) (Brock 2003b); □ *C. praecedens* from the Mandagery Park Formation, Manildra (A n = 6; B, n = 6) (Savage 1969: pl. 92, figs 1–44); *C. praecedens* from the Windellama Limestone, Windellama (A, n = 2; B, n = 1) (Mawson & Talent 1999: pl. 9, figs 15–19); *C. imbricata* from the Garra Limestone, The Gap (A, n = 1; B, n = 3) (Farrell 1992: pl. 5, figs 13–26); *Calceola heteroclita*, type species of *Cyrtina* (A, n = 1; B, n = 1) (Boucot et al. 1965: fig. 549, 10).

Atryparia Copper, 1966a

Type species. By original designation of Copper (1966a: 982); *Atryparia instita* Copper, 1966a; late Eifelian Müllert horizon, Ahbach beds, Germany.

Atryparia penelopeae (Chatterton, 1973)
Fig. 21F-V

Atrypa desquamata-Mitchell & Dun 1920: 271, pl. 15, figs 12, 13.

Desquamatia (*Synatrypa*) sp. nov. Hill, Playford & Woods 1967: pl. 20, figs 15, 16.

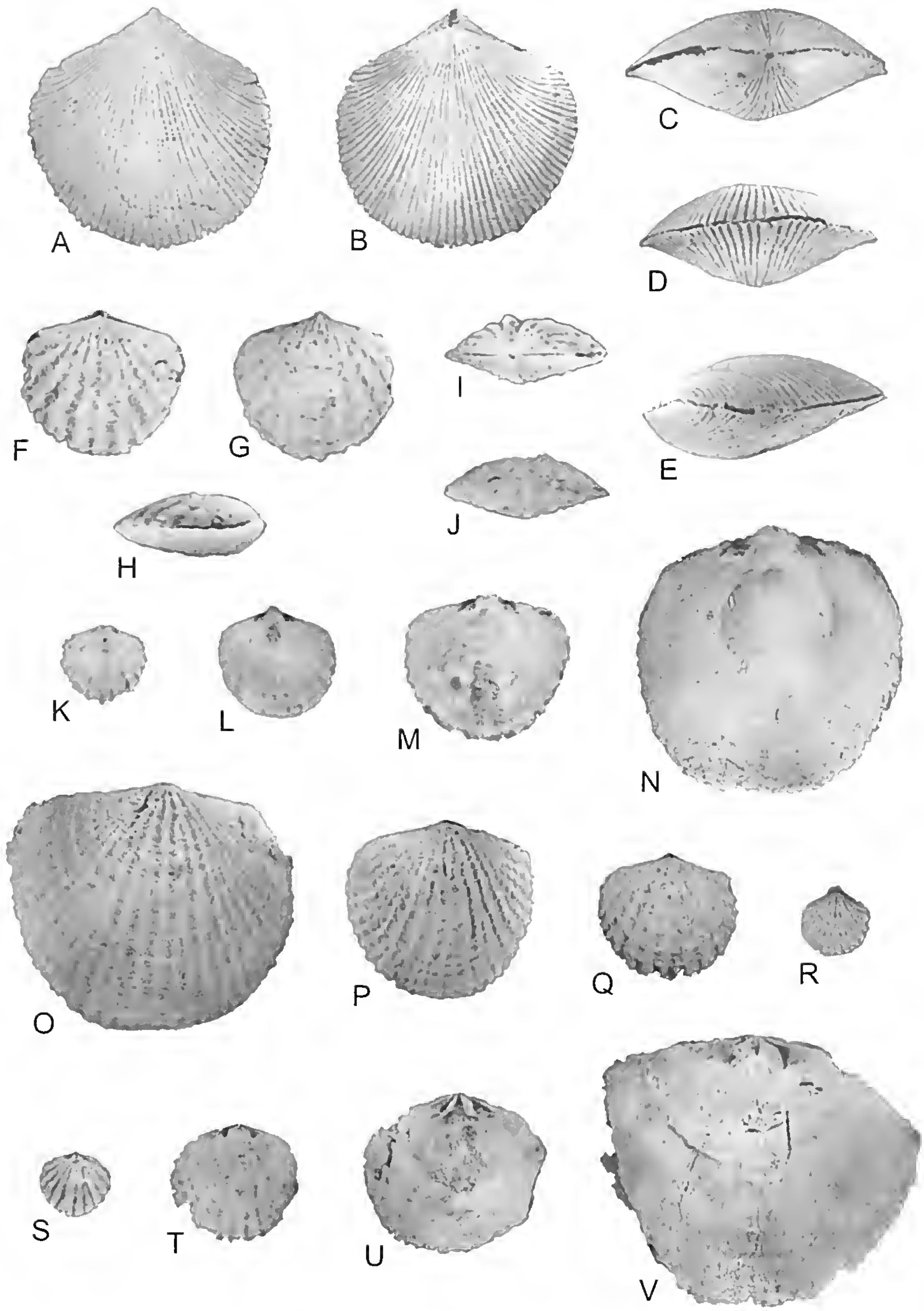
Atrypa penelopeae sp. nov. Chatterton 1973: 87, pl. 20, figs 15, 16; pl. 21, figs 12–23, 25–29; pl. 22, figs 1–10.

Desquamatia (*Variatrypa*) cf. *penelopeae*-Lenz & Johnson 1985b: 78, pl. 4, figs 4–14.

Atryparia penelopeae-Brock & Talent 1993: 239, fig. 11P-R; fig 12A-J.

Material. Figured material: AM F117317 (Fig. 21F-J): articulated specimen from ROC 162; AM F117318 (Fig. 21K): ventral valve from ROC 162; AM F117319 (Fig. 21L): ventral valve from ROC 162; AM F117320 (Fig. 21M): ventral valve from ROC 162; AM F117321 (Fig. 21N): ventral valve from ROC 181; AM F117322 (Fig. 21O): articulated specimen from McL 417; AM F117323 (Fig. 21P): articulated specimen from McL 417; AM F117324 (Fig. 21Q): articulated specimen from ROC 162; AM F117325 (Fig. 21R): articulated specimen from ROC 162; AM F117326 (Fig. 21S): dorsal valve from ROC 162; AM F117327 (Fig. 21T): dorsal valve from ROC 162; AM F117328 (Fig. 21U): dorsal valve from ROC 162; AM F117329 (Fig. 21V): dorsal valve from ROC 162. Unfigured material: 779 ventral valves, 790 dorsal valves and 772 articulated specimens.

Description. See Chatterton (1973: 87).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Remarks. Brock & Talent (1993) believed the shape, growth lines, beak shape, lack of deltidial plates in mature specimens and the secondary thickening of shell material in the delthyrium of this species suggested its affinities lay with *Atryparia*, rather than *Atrypa* Dalman, 1828, where it was originally assigned by Chatterton (1973). Affinities with *Variatrypa* Copper, 1966b can be ruled out as the frill is not composed of a single piece. Unlike *Desquamatia* Alekseeva, 1960, adult specimens of *A. penelopeae* lack a well-developed interarea and possess coarse, rather than fine, costae.

Talent et al. (2001) questionably referred *A. penelopeae to Peetzatrypa* Rzhonsnitskaya, 1975, which occurs in the Eifelian Poluiakhtovsk Beds of the southwestern margin of the Kuzbass. *Peetzatrypa* possesses deltidial plates that are lacking in mature specimens of *A. penelopeae*, and weakly developed dental plates, that are thick and well developed in *A. penelopeae*. *Peetzatrypa* also possesses a high dorsal valve median ridge and spiralia with around ten whorls. *Atryparia penelopeae* has only a low dorsal valve median ridge, which is restricted to dividing the posterior half of the adductor scars and spiralia with as many as nineteen whorls (Chatterton 1973). Copper (2002) has recently synonymised *Peetzatrypa* with *Variatrypa*.

Ontogeny. Neanic specimens of *A. penelopeae* from the Murrindal Limestone are equibiconvex, or slightly ventribiconvex. A weakly developed fold in the ventral valve and sulcus in the dorsal valve may be present. A small pair of deltidial plates are observable in the delthyrium, defining a small, circular foramen (Fig. 21R). Several equally spaced growth lines are also observable with more added at regular intervals throughout growth (Fig. 21R). Muscle scars, if present, are only faintly impressed in each valve. The inner surface is strongly crenulate, a reflection of external ornament (Fig. 21K, S).

The dorsal valve of sub-adults has increased in convexity relative to the ventral valve, making them dorsibiconvex (Fig. 21H). The delthyrium, with its circular foramen and deltidial plates is still observable, but has begun to be reabsorbed (Fig. 21Q). Additional costae have arisen through intercalation and bifurcation (Fig. 21P, Q). Muscle scars are only faintly impressed, with the ventral valve muscle scars being more firmly impressed than those of the dorsal valve (Fig. 21L, M, T, U). Slight pitting occurs in the ventral valve muscle field of some specimens, usually in those with the more firmly impressed muscle scars. The teeth have developed a faintly crenulate ridge running along their length and corresponding crenulated furrows are developed in the sockets of the dorsal valve (Fig. 21M, U). The internal surfaces have lost the strongly crenulated appearance, becoming smoother as the shells increase in size (Fig. 21L, M, T, U).

In adult and gerontic forms, the pedicle has been atrophied and the deltidial plates and foramen are absent, both having been resorbed (Fig. 21N, O). In association with this, secondary thickening of the shell around the delthyrium is prominent. The profile of adult *A. penelopeae* is strongly dorsibiconvex, the ventral valve being almost planar in some specimens. The muscle scars of both valves have become even more deeply impressed, but those of the dorsal valve are less firmly impressed than those of the ventral valve (Fig. 21N, V). A low ridge dividing the posterior portion of the dorsal valve muscle field has also been developed (Fig. 21V). The area around the muscle scars of both valves has become pitted, especially in the ventral valve (Fig. 21N). Stronger pitting is usually associated with more deeply impressed muscle scars. A frill is also developed in some adult and gerontic specimens of *A. penelopeae*.

Subfamily VARIATRYPINAE Copper, 1978

Variatrypa (Variatrypa) Copper, 1966b

Type species. By original designation of Copper (1966b: 12); *Desquamatia ajugata* Copper, 1965; lower Givetian Neuenbüsch horizon of the Blankenheim Syncline, northern Eifel, Germany.

Remarks. Copper (1966b) established *Variatrypa* as a subgenus of *Desquamatia*, but subsequently raised it to generic level (Copper 1978, 1991, 2002), diagnosing it as large, shield-shaped, dorsibiconvex with only one or two growth lines and a frill that is normally a single piece. According to Copper (1978: 294), *Anatrypa* may be distinguished from *Variatrypa* by its

Fig. 21. A-E, *Variatrypa* (*Variatrypa*) *erectirostris* (Mitchell & Dun, 1920), ventral, dorsal, posterior, anterior and lateral views of articulated specimen, McL 417, AM F117316, x 2. F-V, *Atryparia penelopeae* (Chatterton, 1973). All specimens x 2. F-J, dorsal, ventral, lateral, posterior and anterior views of articulated specimen, ROC 162, AM F117317. K-N, all ventral valve interiors. K-M, ROC 162, N, ROC 181, AM Fs117318-117321. O-R, all dorsal view of articulated specimens. O, P, McL 417, Q, R, ROC 162, AM Fs 117322-117–325. S-V, all dorsal valve interiors, ROC 162, AM Fs 117326-117329.

biconvex profile, transversely subpentagonal outline, deltidial plates supported well into the interior of the pedicle cavity, medially directed teeth, thinner hinge plates, weakly developed cardinal process and thicker, ventrally directed crural bases. In contrast, Johnson & Boucot (1968) and Johnson (1970b, 1974a) argued that *Variatrypa* is best regarded as a subgenus of *Anatrypa*, due to similarities in ornament, the ventral valve interarea and delthyrium. The differences in shell shape between the type species of *Anatrypa* and *Variatrypa* were considered by Johnson & Boucot (1968) to be insignificant at the generic level. However, based on the differences discussed above, there seems sufficient differences between *Variatrypa* and *Anatrypa* to warrant a separate generic status for each.

Variatrypa (Variatrypa) erectirostris
(Mitchell & Dun, 1920)
Figs 19S-V, 21A-E

Atrypa erectirostris Mitchell & Dun 1920: 267, pl. 15, figs 10, 11; pl. 16, figs 17, 18.
Anatrypa erectirostris-Chatterton 1973: 92, pl. 20, figs 1–14, 17; pl. 21, figs 1–11, 24, 30–32; pl. 22, figs 11, 12.
Variatrypa (*Variatrypa*) *erectirostris*-Brock & Talent 1993: 243, fig. 12K-O; fig. 13 F-P.

Material. Figured material: AM F117314 (Fig. 19S, T): ventral valve from MeL 417; AM F117315 (Fig. 19U, V): dorsal valve from ROC 162; AM F117316 (Fig. 21A-E): articulated specimen from MeL 417. Unfigured material: 70 ventral valves, 30 dorsal valves and 106 articulated specimens.

Description. See Mitchell & Dun (1920: 267) and Chatterton (1973: 92).

Remarks. Chatterton (1973) declined to place this species from the Emsian '*Receptaculites*' Limestone Member at Taemas, into either of the subgenera proposed by Copper (1966b) for *Anatrypa*. Chatterton (1973) believed this species to be larger than *A.* (*Synatrypa*) and possessing a ventral valve that is concave anterolaterally (Fig. 21C, D), and to be distinct from *A.* (*Variatrypa*) because it lacked a frill and possesses finer and more closely spaced costae (Figs 19S, V, 20A, B). However, Chatterton (1973) did note this species is probably closest to those forms assigned to *A.* (*Variatrypa*). Brock & Talent (1993) provisionally reassigned this species to *Variatrypa* (*Variatrypa*), following Copper (1978, 1991), on the basis of the fine ribbing being interrupted by only a few growth lamellae. In addition, some specimens from the Murrindal Limestone, unlike those described by Chatterton (1973), possess growth lamellae developed into frills, further reinforcing this species affinities with *Variatrypa*.

Suborder DAYIINA Waagen, 1883
Superfamily ANOPLOTHECOIDEA
Schuchert, 1894
Family ANOPLOTHECIDAE Schuchert, 1894

Remarks. Following Johnson (1974b), Dagys (1996), Alvarez & Carlson (1998) and Alvarez et al. (1998), the Anoplothecidae (which includes *Coelospira* Hall, 1863, discussed below) are assigned to the superfamily Anoplothecoidea (following Alvarez et al. 1998) within the suborder Dayiina (following Johnson 1974b) in the order Atrypida. Although fundamental differences do exist between the Dayiina and the other atrypid suborders, and confusion surrounds their evolutionary relationships, there appears little justification at present to warrant their inclusion within the Athyrida as proposed by Copper (1973, 1986), Copper & Gourvennec (1996) and Alvarez & Copper (2002).

Subfamily COELOSPIRINAE Hall & Clark, 1895

Coelospira Hall, 1863

Type species. By original designation of Hall (1863: 60); *Leptocoelia concava* Hall, 1857; Lochkovian of the lower Helderberg Group, Helderberg Mountain, New York, America.

Coelospira dayi Chatterton, 1973
Fig. 19L-R

Coelospira dayi sp. nov. Chatterton 1973: 84, pl. 19, figs 15–36; pl. 35, figs 6–8.

Material. Figured material: AM F117312 (Fig. 19L-P): articulated specimen from MeL 497; AM F117313 (Fig. 19Q, R): ventral valve from MeL 497. Unfigured material: four ventral valves and 12 articulated specimens.

Description. See Chatterton (1973: 84).

Remarks. *Coelospira concava* (see Boucot & Johnson 1967: 1235-1236 for locality information) shows considerable morphological variation, espe-

cially in the length to width ratio and in the character of the median rib of the ventral valve. *Coelospira dayi* differs most consistently from *C. concava* in having a ventral valve muscle field that is not anteriorly elevated on a platform.

Coelospira dayi was the first species of *Coelospira* to be documented in Australia. Previously, Devonian *Coelospira* were believed to have been restricted to Laurentia, apart from a single specimen recovered from Turkey (Boucot & Johnson 1967). However, since then *Coelospira* has also been recovered from northern Mexico, South America and Asia, ranging from Lochkovian to Eifelian in age (Alvarez & Copper 2002). Several additional species of *Coelospira* have also been described from Australia.

Coelospira praedayi Lenz & Johnson, 1985b, from the Pragian Garra Limestone at Wellington is closely related to *C. dayi*. Both species have a similar shape and ornament, but *C. dayi* is more elongate, possesses a shorter median costa on the ventral valve and shorter, weaker secondary costae. *Coelospira septata* Lenz & Johnson, 1985b, also from the Pragian Garra Limestone at Wellington (Lenz & Johnson 1985b) and the Pragian Garra Limestone at Eurimbla (Brock 2003b), is more rounded, possesses more costae in the dorsal valve sulcus compared to *C. dayi* and has a thread-like median ridge in the ventral valve and a prominent median septum in the dorsal valve (Lenz & Johnson 1985b). An indeterminate specimen referred to as Coelospirinae gen. indet. by Savage (1974) from the ?early Lochkovian Maradana Shale has been referred to *Coelospira* by Talent et al. (2001). This species differs primarily from *C. dayi* in bearing more costae.

Coelospira sp., documented by Brock & Talent (1993) from the Emsian Ukalunda Beds and Douglas Creek of Queensland, possesses a similar outline, incurvature of the beak and growth lines to *C. dayi*. However, *C. dayi* is distinguishable by its well-developed dorsal valve sulcus (Fig. 19L, N) and ventral valve with a fine medial plication flanked by a pair of large costae (Fig. 19M, R). The Ukalunda and Douglas Creek specimens also possess a number of features unique to *Coelospira*, such as the presence of up to three well developed ventral medial costae and costae which increase by bifurcation on the ventral valve and usually by implantation on the dorsal valve. Brock & Talent (1993: 239) speculated that this unusual combination of features may indicate these specimens represent a new species of *Coelospira*, but additional material is required to confirm this. Hill et al. (1967: pl. D12, fig. 6) figured a single specimen of *Coelospira* from the Ukalunda Beds that appears externally similar to those specimens described by Brock & Talent (1993), although it has a somewhat narrower outline.

Order ATHYRIDIDA Boucot, Johnson & Stanton, 1964
Suborder ATHYRIDINA Boucot, Johnson & Stanton, 1964
Superfamily ATHYRIDOIDEA Davidson, 1881
Family ATHYRIDIDAE Davidson, 1881
Subfamily DIDYMOTHYRIDINAE Modzalevskaia, 1979

Buchanathyris Talent, 1956a

Type species. By original designation of Talent (1956a: 36); *Buchanathyris westoni* Talent, 1956a; Early Emsian Buchan Caves Limestone, Buchan, Victoria, Australia.

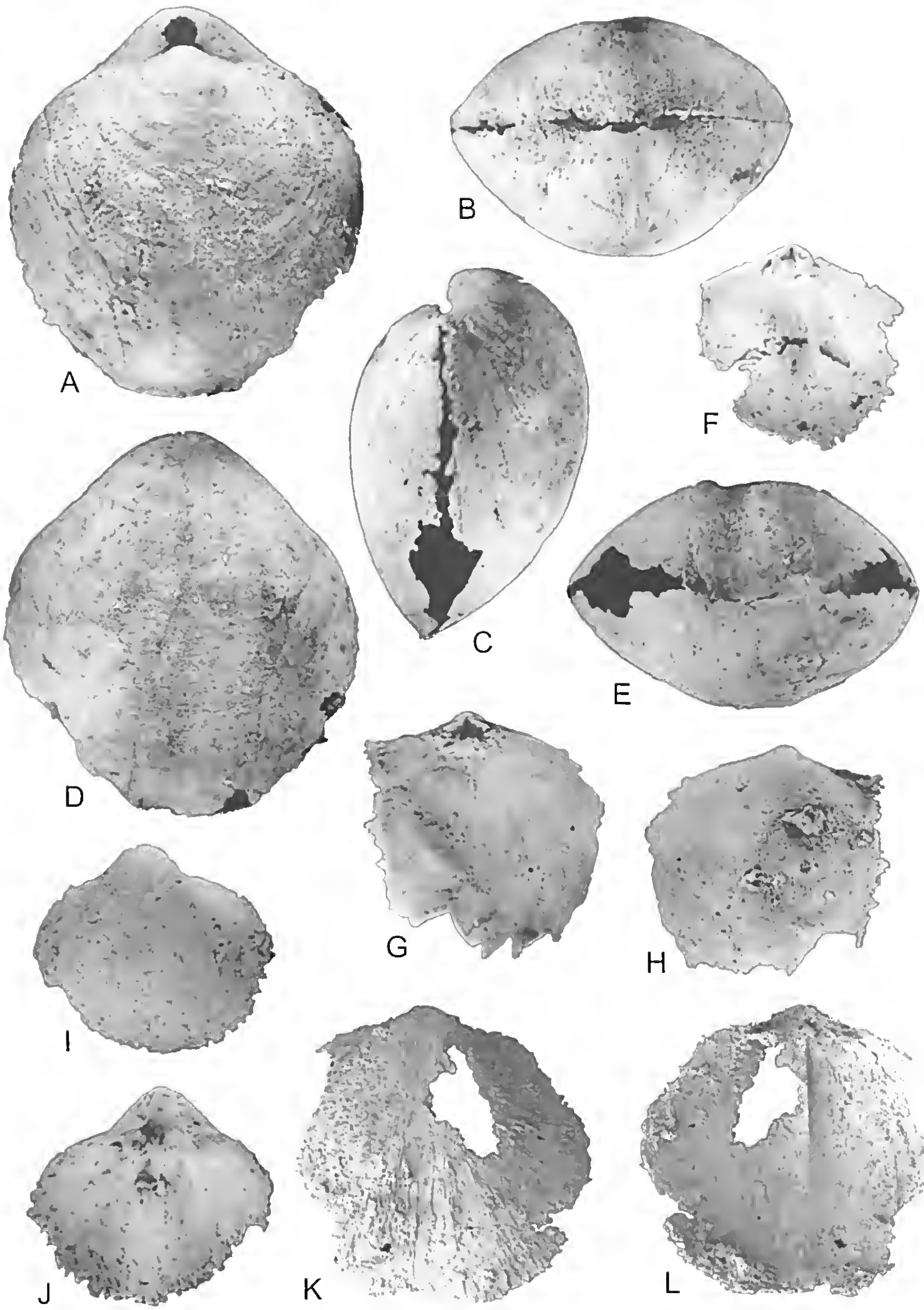
Buchanathyris westoni Talent, 1956a
Fig. 22A-J

Buchanathyris westoni sp. nov. Talent 1956a: 36, pl. 3, figs 1–4.
Buchanathyris westoni?-Talent 1963: 87, pl. 59, figs 5–11.

Material. Figured material: AM F117330 (Fig. 22A-E): articulated specimen from ROC 162; AM F117331 (Fig. 22F): dorsal valve from ROC 162; AM F117332 (Fig. 22G, H): dorsal valve from ROC 165; AM F117333 (Fig. 22I, J): ventral valve ROC 162. Unfigured material: 210 ventral valves, 229 dorsal valves and 32 articulated specimens.

Description. See Talent (1956a: 36).

Remarks. Although no features of the lophophore support or jugum have been preserved, the presence of a short and apically perforated hinge plate, fairly well developed concave dental plates and lack of a median septum (Fig. 22F, G, J), indicates the affinities of this taxon lie with *Buchanathyris*. The ornament, consisting of fine concentric growth lines at best (Fig. 22A, D), associates these specimens with *B. westoni*, which also occurs in the early Emsian Buchan Caves Limestone and Pragian Dead Bull Member of the Tabberabbera Formation of Victoria (Talent 1956a). The ornament also separates this species from *B. waratahensis* Talent, 1956a, from the latest Pragian Bell Point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Limestone in Victoria, which possesses projecting growth lines. *Buchanathyris*? *pulchra* Talent, 1963 (questionably referred to *Athyris*? by Talent et al. 2001) from the ?early Emsian Roaring Mag Member of the Tabberabbera Formation of Victoria, differs from *B. westoni* in possessing a well defined sulcus in the ventral valves, a poorly developed fold in the dorsal valve and well developed growth lamellae.

The majority of the specimens recovered from the Murrindal Limestone differ from Talent's (1956a) original description of *B. westoni* in possessing a thread-like median ridge in the dorsal valve that extends anteriorly to approximately valve midlength. Associated with this ridge are long, thin impressions of muscle scars which extend forward no further than the median ridge (Fig. 22F, G). These two features are highly variable and at any given stratigraphic horizon they range from indistinct to strongly developed. Talent (1963) did not mention the presence or absence of dorsal muscle scars in *B. westoni* from the Buchan Caves Limestone, but he stated that the dorsal valve lacked a median septum. Talent (1963) described *B. westoni*? from the Tabberabbera Formation as possessing elongate muscle scars in the dorsal valve and a variably developed, often faint, median septum.

Buchanathyris has also been recovered from China. *Buchanathyris subplana* (Tien, 1938), from the Devonian of Sichuan Province (Wang et al. 1974) is slightly more elongate, but is not as thick and has a weaker beak and smaller foramen compared to *B. westoni*.

Superfamily NUCLEOSPIROIDEA Davidson, 1881
Family NUCLEOSPIRIDAE Davidson, 1881

Nucleospira Hall in Davidson, 1858b

Type species. By monotypy, Hall in Davidson (1858b: 412); *Spirifer ventricosus* Hall, 1857; Lochkovian of the lower Helderberg Group, Helderberg Mountain, New York, America.

Nucleospira sp.
Fig. 22K, L,

Material. Figured material: AM F117334 (Fig. 22K, L): ventral valve from McL 495. Unfigured material: one ventral valve.

Remarks. It is not possible to assign the Murrindal specimens to a described species of *Nucleospira* due to the limited and inadequately preserved material. However, the shells appear to differ from most other described species of *Nucleospira* in that the median septum of the ventral valve does not extend beyond valve midlength. The Murrindal specimens appear most similar to those described by Philip (1962) from the late Lochkovian Boola Siltstone of the Tyers-Boola area of central Victoria and Talent (1963) from the Pragian Lower Kilgower Member of the Tabberabbera Formation. The Tyers Boola specimens possess a median septum with an ill-defined anterior portion (Philip 1962), whereas the length of the median septum is variable in the Tabberabbera specimens (Talent 1963).

Based on this difference in the length of the median septum alone, the Murrindal specimens may represent a new species of *Nucleospira*. However, most species of *Nucleospira* are very similar externally and internally (Savage 1981). Bowen (1967: 38) and Savage (1981: 366) both stated that new species of *Nucleospira* are assigned primarily on differences in the distinctiveness of the sulcus, valve convexity, the length to width ratio, growth lines and size. It is difficult to determine these characteristics for the Murrindal specimens. In addition, these characteristics appear highly variable both between and within species and the range of variation between species remains unknown (Bowen 1967; Savage 1981). As a result, many workers, such as Johnson (1970a), Harper (1973), Boucot (1973) and Smith (1980), have declined to name individual species.

Order TEREBRATULIDA Waagen, 1883

Remarks. The higher level classification used for the Terebratulida herein follows that of Boucot & Wilson (1994).

Suborder CENTRONELLIDINA Stehli, 1965
Superfamily STRINGOCEPHALOIDEA King, 1850
Family MEGANTERIDAE Schuchert & Levene, 1929
Subfamily ADRENINAE Boucot in Boucot & Wilson, 1994

Fig. 22. A-J, *Buchanathyris westoni* Talent, 1956a. All specimens x 3. A-E, dorsal, posterior, lateral, ventral and anterior views of articulated specimen, ROC 162, AM F117330. F, dorsal valve interior, ROC 162, AM F117331. G, H, dorsal valve interior and exterior, ROC 165, AM F117332. I, J, ventral valve exterior and interior, ROC 162, AM F117333. K, L, *Nucleospira* sp., ventral valve exterior and interior, McL 495, AM F117334, x 18.

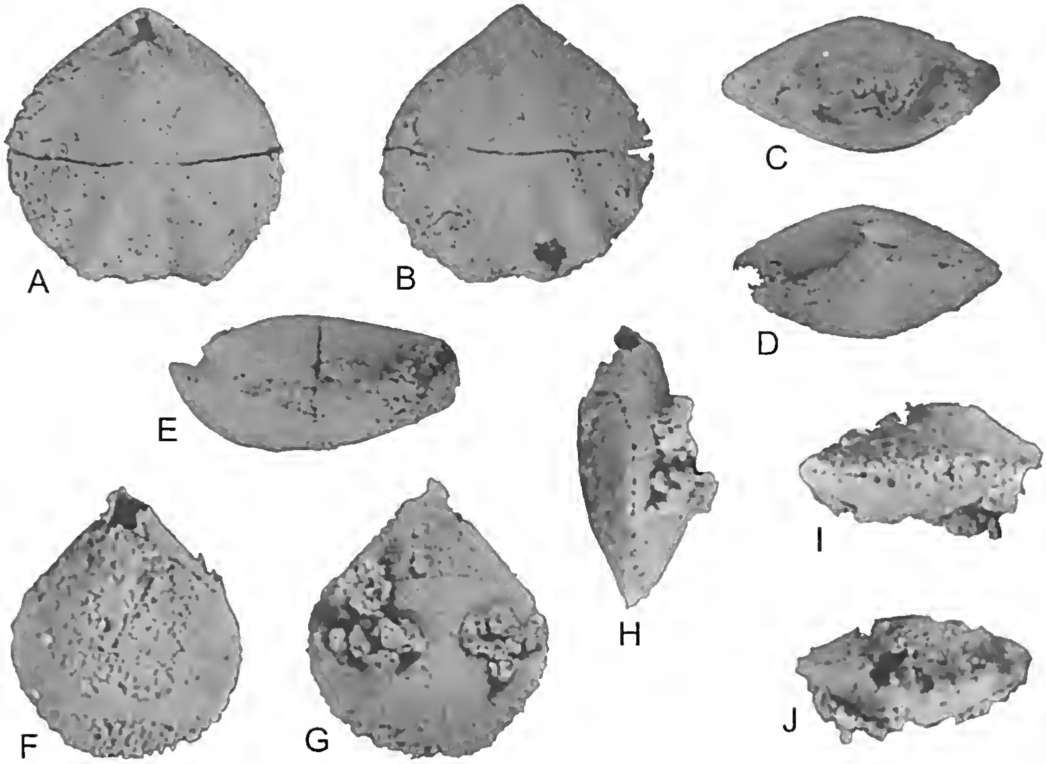

Fig. 23. A-E, *Micidus shandkyddi* Chatterton, 1973, dorsal, ventral, anterior, posterior and lateral views of articulated specimen, ROC 162, AM F117335, x 5. F-J, *Micidus? glaber* Chatterton, 1973, dorsal, ventral, lateral, anterior and posterior views of articulated specimen, McL 497, AM F117336, x 12.

Micidus Chatterton, 1973

Type species. By original designation of Chatterton (1973: 137); *Micidus shandkyddi* Chatterton, 1973; early Emsian '*Receptaculites*' Limestone Member, Taemas Limestone, Taemas, New South Wales, Australia.

Micidus shandkyddi Chatterton, 1973
Fig. 23A-E

Micidus shandkyddi gen. et sp. nov. Chatterton 1973: 137, pl. 34, figs 1–12.

?*Micidus*? spp. A. Lenz & Johnson, 1985b: 93, pl. 16, figs 7–24.

?*Micidus*? spp. B Lenz & Johnson 1985b: 93, pl. 16, figs 20, 25–35.

Material. Figured material: AM F117335 (Fig. 23A-E): articulated specimen from ROC 162. Unfigured material: two dorsal valves and 22 articulated specimens.

Description. See Chatterton (1973: 137).

Remarks. Chatterton (1973) separated *M. shandkyddi* from *M? glaber* Chatterton, 1973, primarily on differences in external features. These include the presence of anterolateral plications, a weakly developed fold and sulcus, a weakly sulcate anterior commissure and a submesothyridid (to hypothyridid?) foramen in *M. shandkyddi*. The external features and dimensions of the Murrindal specimens compare well with *M. shandkyddi* from the Emsian '*Receptaculites*' Limestone Member, although the Murrindal specimens are slightly larger (Fig. 24). It is not possible to compare internal features though as none of the specimens recovered from the Murrindal Limestone shows any trace of internal preservation.

Lenz & Johnson (1985b) tentatively referred two species from the Pragian Garra Limestone at Wellington to *Micidus* as they possessed simple deltidial plates. *Micidus*? spp. A closely resembles *M. shandkyddi*, both possessing a similar number of

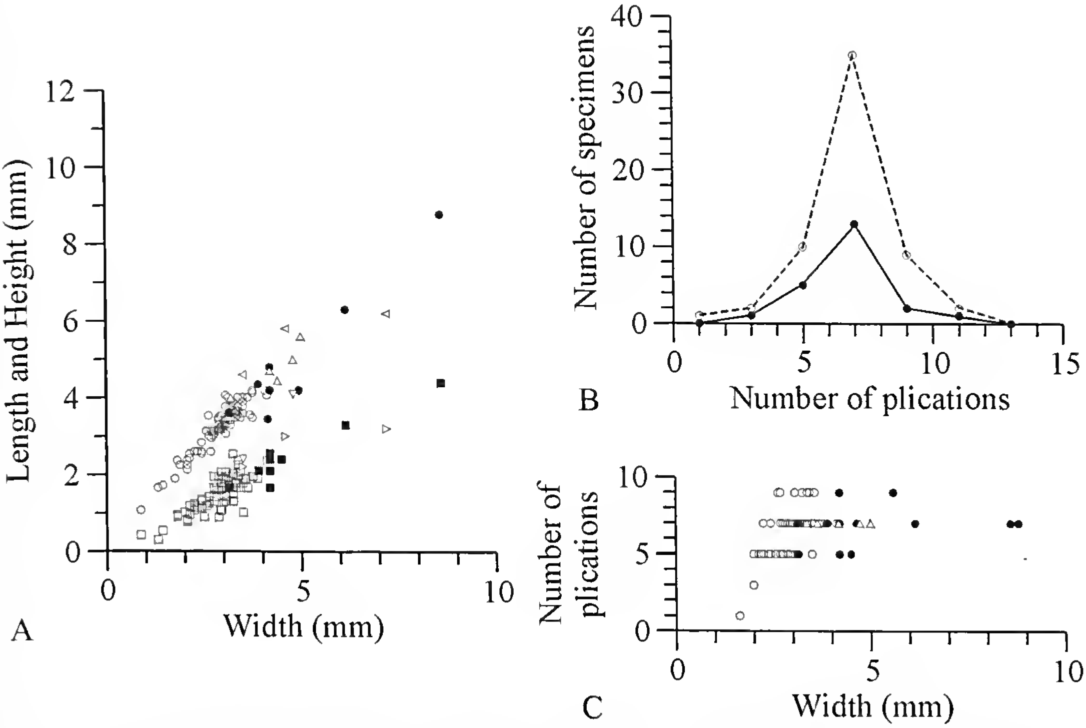

Fig. 24. Comparison of *M. shandkyddi* from the '*Receptaculites*' Limestone Member at Taemas (average width 2.87 mm; length 3.22 mm; height 1.5 mm; number of plications 6.9) (Chatterton 1973: fig. 49), with *M. shandkyddi* from the Murrindal Limestone (average width 4.71 mm; length 4.96 mm; height 2.42 mm; number of plications 6.73) and *M.* spp. A from the Garra Formation (average width 4.15 mm; length 4.75 mm; height: 3.25 mm; number of plications 7) (Lenz & Johnson 1985b: pl. 16, figs 7–24) and *M?* spp. B. from the Garra Formation (average width 5.1 mm; length 5.53 mm; height 2.8 mm) (Lenz & Johnson 1985b: pl. 16, figs 20, 25–35). A, Length versus width of ● Murrindal specimens (n = 8), ○ Taemas specimens (n = 72), △ *M.* spp. A (n = 4) and ◁ *M?* spp. B (n = 3); height versus width of ■ Murrindal specimens (n = 10), □ Taemas specimens (n = 75), ▽ *M.* ssp. A (n = 2) and ▷ *M?* spp. B (n = 3). B, Number of specimens versus number of plications of -●- Murrindal (n = 22) and -○- Taemas specimens (n = 60). C, Number of plications versus width of ● Murrindal specimens (n = 13), ○ Taemas specimens (n = 45) and △ *M.* spp. A (n = 5).

plications and dimensions, although they too are somewhat larger than *M. shandkyddi* (Fig. 17). The Garra specimens differ, however, in possessing sharply rounded to angular plications. *Micidus*? spp. B possesses 2–3 pairs of rounded to angular costae that are at best weakly developed on the anterior half to third of the valve, compared to 5–11 plications on the dorsal valve of *M. shandkyddi*. Despite this external difference from *M. shandkyddi*, Lenz & Johnson (1985b) note that the crural plates and loops of *M?* spp. B are the same as those in *M?* spp. A.

Micidus stellae Soja, 1988, from the Emsian of Kasaan Island, southeastern Alaska, differs in having fewer plications along the anterior margins (three on the dorsal valve and two on the ventral valve) and inner hinge plates that are united anteriomedially.

Micidus? glaber Chatterton, 1973
Fig. 23F-J

Micidus? glaber sp. nov. Chatterton 1973: 138, pl. 30, figs 1–15.

Material. Figured material: AM F117336 (Fig. 23F-J): articulated specimen from MeL 497. Unfigured material: 31 articulated specimens.

Description. See Chatterton (1973: 138).

Remarks. Chatterton (1973) tentatively referred this species from the top of the Emsian '*Receptaculites*' Limestone Member to *Micidus* due to internal similarities with *M. shandkyddi*, despite the fact it dif-

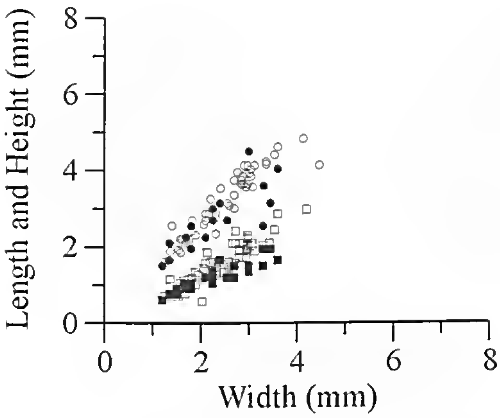

Fig. 25. Comparison of *M*? *glaber* from the '*Receptaculites*' Limestone Member at Taemas (average width 2.51 mm; length 3.19 mm; height 1.65 mm) (Chatterton 1973: fig. 50), with *M*? *glaber* from the Murrindal Limestone (average width 2.33 mm; length 2.73 mm; height 1.23 mm). Length versus width of ● Murrindal (n =16) and ○ Taemas specimens (n = 53). Height versus width of ■ Murrindal (n = 23) and □ Taemas specimens (n = 53).

fered in lacking plications. The Murrindal specimens closely resemble *M*? *glaber* externally (Fig. 25). No specimens with internal structures preserved have been recovered from the Murrindal Limestone and the exact taxonomic status of this species must therefore remain doubtful.

Micidus stellae Soja, 1988, from the Emsian of Kasaan Island, southeastern Alaska, is easily distinguished by the presence of three plications developed along the anterior margin of the dorsal valve and two on the ventral valve.

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This report is a contribution towards documentation of the brachiopod faunas of the Murrindal Limestone, and to IGCP Project 421: *North Gondwana mid-Palaeozoic bioevent/biogeography patterns in relation to crustal dynamics*.

REFERENCES

AMSDEN, T. W., 1968. Articulate brachiopods of the St. Clair Limestone (Silurian), Arkansas, and the Clarita Formation (Silurian), Oklahoma. *Paleontographical Society Memoir* 1: 1–117.

AMSDEN, T. W., 1974. Late Ordovician and Early Silurian articulate brachiopods from Oklahoma, southwestern Illinois and eastern Missouri. *Oklahoma Geological Survey Bulletin* 119: 1–154.

ALBERTI, G. K. B., 1993. Dacryoconaride und homoctenide Tentaculiten des Unter- und Mittel-Devons I. *Courier Forschungsinstitut Senckenberg* 158: 1–229.

ALBERTI, G. K. B., 1995. Planktonic tentaculitid correlation with conodont zonation in the south-east Australian Lower Devonian. *Courier Forschungsinstitut Senckenberg* 182: 557–558.

ALEKSEEVA, R. E., 1960. O novom podrode *Atrypa* (*Desquamatia*) subgen. semevstva Atrypidae Gill (Brakhiopody). *Doklady Akademii Nauk SSSR* 131: 421–424.

ALVAREZ, F. & CARLSON, S. J., 1998. Evolución y relaciones filogenéticas entre los grupos de mayor rango taxonómico de atíridos y otros "braquiópodos articulados". *Revista Española de Paleontología* 13: 209–234.

ALVAREZ, F. & COPPER, P. 2002. Uncertain. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 4: Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 1604–1614.

ALVAREZ, F., RONG JIA-YU & BOUCOT, A. J., 1998. The classification of athyrid brachiopods. *Journal of Paleontology* 72: 827–855.

ANDERSON, M. M., BOUCOT, A. J. & JOHNSON, J. G., 1969. Eifelian brachiopods from Padaukpin, northern Shan States, Burma. *Bulletin of the British Museum of Natural History (Geology)* 18: 105–163.

Bancroft, B. B., 1928. On the notational representation of the rib system in Orthacea. *Memoir and Proceedings of the Manchester Literary and Philosophical Society* 72: 52–90.

Bancroft, B. B., 1945. The brachiopod zonal indices of the stages Costonian-Onnian in Britain. *Journal of Paleontology* 19: 181–252.

Barrande, J., 1847. Über die Brachiopoden der silurischen Schichten von Böhmen. *Naturwissenschaftliche Abhandlungen* 1: 357–475.

Barrande, J., 1848. Über die Brachiopoden der silurischen Schichten von Böhmen. *Naturwissenschaftliche Abhandlungen* 2: 155–256.

Barrande, J., 1879. *Système Silurien du centre de la Bohême. Recherches paléontologiques, vol. 5. Classe des Mollusques. Ordre des Brachiopodes*. Published by the author, Prague and Paris, xiv+226 pp.

Basden, A., 1999. Emsian (Early Devonian) microvertebrates from the Buchan and Taemas areas of southeastern Australia. *Records of the Western Australian Museum, Supplement* 57: 15–22.

Bell, K. N., 1996. Early Devonian (Emsian) agglutinated foraminiferans from Buchan and Bindi, Victoria, Australia. *Proceedings of the Royal Society of Victoria* 108: 73–106.

Bell, K. N. & Winchester-Seeto, T. M., 1999. Linings of agglutinated foraminifera from the Devonian: taxonomic and biostratigraphic implications. *Journal of Micropalaeontology* 18: 27–43.

Biernat, G., 1959. Middle Devonian Orthoidea of the Holy Cross Mountains and their ontogeny. *Palaeontologica Polonica* 10: 1–78.

Biernat, G. & Bednarczyk, W., 1990. Evolutionary crisis within the Ordovician acrotretid inarticulate brachiopods of Poland. In Extinction Events in Earth History, E. G. Kaufman & O. H. Walliser, eds. *Lecture Notes in Earth History 30*: 105–114.

Biernat, G. & Harper, D. A. T., 1999. A lingulate brachiopod *Acrotretella*: new data from Ordovician of Poland. *Acta Palaeontologica Polonica* 44: 83–92.

Boucot, A. J., 1973. Early Paleozoic brachiopods of the Moose River Synclinorium, Maine. *United States Geological Survey Professional Paper* 784: 1–81.

Boucot, A. J. & Johnson, J. G., 1967. Species and distribution of *Coelospira* (Brachiopoda). *Journal of Paleontology* 41: 1226–1241.

Boucot, A. J., Johnson, J. G., Pitrat, C. W. & Staton, R. D., 1965. Spiriferida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, volume 2*, R. C. Moore, ed. Geological Society of America and University of Kansas Press, Lawrence, H632–H728.

Boucot, A. J. & Wilson, R. A., 1994. Origin and early radiation of terebratuloid brachiopods: thoughts provoked by *Prorensselaeria* and *Nanothyris*. *Journal of Paleontology* 68: 1002–1025.

Bowen, Z. P., 1967. Brachiopoda of the Kayser Limestone (Silurian-Devonian) of Maryland and adjacent areas. *Geological Society of America Memoir* 102: 1–103.

Brock, G. A., 1989. *Middle Devonian (Givetian) atrypids from the Papilio Formation, north Queensland, Australia*. MSc thesis, Macquarie University, Sydney (unpubl.).

Brock, G. A., 2003a. Lochkovian (Early Devonian) brachiopods from the Garra Limestone at Eurimbla, New South Wales, Australia. Part 1: Aerotretida, Strophomenida, Productida, Orthotetida, Orthida and Pentamerida. *Palaeontographica Abt.* A 269: 93–136.

Brock, G. A., 2003b. Lochkovian (Early Devonian) brachiopods from the Garra Limestone at Eurimbla, New South Wales, Australia. Part 2: Rhynchonellida, Atrypida, Athyridida and Spiriferida. *Palaeontographica Abt. A* 270: 49–94.

Brock, G. A., Engelbretsen, M. J. & Dean-Jones, G., 1995. Acrotretoid brachiopods from the Devonian of Victoria and New South Wales. *Memoirs of the Association of Australasian Palaeontologists* 18: 105–120.

Brock, G. A. & Talent, J. A., 1993. Emsian (Early Devonian) brachiopods from the Ukalunda Beds and Douglas Creek, north Queensland. *Memoirs of the Association of Australasian Palaeontologists* 15: 225–248.

Brunton, C. H. C. & Cocks, L. R. M., 1996. The classification of the brachiopod order Strophomenida. In *Brachiopods*, P. Copper & J. Jin, eds. A.A. Balkema, Rotterdam, 47–51.

Burrow, C. J. & Turner, S., 1998. Devonian placoderm scales from Australia. *Journal of Vertebrate Paleontology* 18: 677–695.

CAMPBELL, K. S. W. & TALENT, J. A., 1967. *Malurostrophia*, a new genus of stropheodontid brachiopod from the Devonian of Australia. *Proceedings of the Royal Society of Victoria* 80: 309–330.

CARTER, J. L., JOHNSON, J. G., GOURVENNEC, R. & HOU HONG-FEI, 1994. A revised classification of the spiriferid brachiopods. *Annals of the Carnegie Museum* 63: 327–374.

CASTER, K. E., 1939. A Devonian fauna from Colombia. *Bulletins of American Paleontology* 24: 1–218.

CHAPMAN, F., 1905. New or little-known Victorian fossils in the National Museum, Melbourne: part VI.-Notes on Devonian spirifers. *Proceedings of the Royal Society of Victoria* 18: 16–19.

CHAPMAN, F., 1913. New or little-known Victorian fossils in the National Museum, part 16, some Silurian Brachiopoda. *Proceedings of the Royal Society of Victoria* 26: 99–113.

CHAPMAN, F., 1914. *Australasian fossils*. G. Robertson & Co., Melbourne, 341 pp.

CHATTERTON, B. D. E., 1973. Brachiopods of the Murrumbidgee Group, Taemas, New South Wales. *Bureau of Mineral Resources, Geology and Geophysics Bulletin* 137: 1–146.

CHATTERTON, B. D. E. & PERRY, D. G., 1978. An early Eifelian invertebrate faunule, Whittaker Anticline, northwestern Canada. *Journal of Paleontology* 52: 28–39.

CHEN XIU-QIN, KUANG GUO-DUN & RONG JIA-YU, 1989. Brachiopods of the Luhui Member of the Dale Formation (late Emsian), Xiangzhou, central Guangxi. *Memoirs of the Nanjing Institute of Geology and Palaeontology* 25: 213–232.

Chlupáč, I., 1976. The oldest goniatite faunas and their stratigraphical significance. *Lethaia* 9: 303–315.

COCKS, L. R. M., 1979. New acrotretacean brachiopods from the Palaeozoic of Britain and Austria. *Palaeontology* 22: 93–100.

COCKS, L. R. M. & RONG JIA-YU, 2000. Strophomenida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 2: Linguliformea, Craniiformea, and Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Lawrence, 216–349.

CONRAD, T. A., 1842. Observations on the Silurian and Devonian systems of the US with descriptions of new organic remains. *Journal of the Academy of Natural Sciences of Philadelphia* 8: 228–280.

COPPER, P., 1965. A new Middle Devonian atrypid brachiopod from the Eifel of Germany. *Senckenbergiana lethaea* 46: 309–325.

COPPER, P., 1966a. European Mid-Devonian correlations. *Nature* 209: 982–984.

COPPER, P., 1966b. The *Atrypa zonata* brachiopod group in the Eifel, Germany. *Senckenbergiana lethaea* 46: 309–325.

COPPER, P., 1973. *Bifida* and *Kayseria* (Brachiopoda) and their affinity. *Palaeontology 16*: 117–138.

COPPER, P., 1978. Devonian atrypoids from western and northern Canada. *Geological Association of Canada Special Papers* 18: 289–331.

COPPER, P., 1986. Filter-feeding and evolution in early spire-bearing brachiopods. In Les Brachiopodes fossiles et actuels, P. R. Racheboeuf & C. C. Emig, eds. *Biostratigraphie du Paléozoïque* 4: 219–230.

COPPER, P., 1991. Evolution of the atrypid brachiopods. In *Brachiopods Through Time*, D. I. MacKinnon, D. E. Lee & P. J. D. Campbell, eds. A.A. Balkema, Rotterdam, 35–40.

COPPER, P., 2002. Atrypida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 4: Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 1377–1474.

COPPER, P. & GOURVENNEC, R. 1996. Evolution of the spire-bearing brachiopods (Ordovician-Jurassic). In *Brachiopods*, P. Copper & J. Jin, eds. A.A. Balkema, Rotterdam, 81–88.

DAGYS, A., 1996. On the classification of the order Athyridida. In *Brachiopods*, P. Copper & J. Jin, eds. A.A. Balkema, Rotterdam, 89–90.

DALMAN, J. W., 1828. Uppställning och Beskrifning af de i Sverige funne Terebratuliter. *Kongliga Svenska Vetenskapsakademien Handlingar for 1827* 3: 85–155.

DAVIDSON, T., 1858a. A monograph of the British fossil Brachiopoda: Part 5, Carboniferous. *Palaeontographical Society* 5: 1–280.

DAVIDSON, T., 1858b. Palaeontological notes on the Brachiopoda, no. 1. On genera and sub-

genera of Brachiopoda that are provided with spiral appendages for the support of the oral arms, and species so constructed, which have been discovered in British Carboniferous strata. *Geologist* 1: 409–416, 457–331.

DEFRANCE, M. J. L., 1824. *Dictionnaire des Sciences Naturelles* 32: 1–306.

DE KONINCK, L. G., 1876. Recherches sur les fossiles Paléozoïques de la Nouvelle-Galles du Sud (Australie). *Mémoires du Société Royale des Sciences de Liège* 3: 25–52.

DE KONINCK, L. G., 1898. Descriptions of the Palaeozoic fossils of New South Wales (Australia). (Translated by T. W. E. David, Mrs David & W. S. Dun from de Koninck 1876). *Memoirs of the Geological Survey of New South Wales, Palaeontology* 6: 1–298.

D'ORBIGNY, A., 1850. *Prodrome de paléontologie stratigraphe universelle des animaux mollusques et rayonnés, vol.* 1. Victor Mason, Paris, lx+349 pp.

DROT, J., 1964. Rhynchonelloidea et Spiriferoidea Siluro-Dévoniens du Maroc présaharien. *Notes et Mémoires Service Géologique du Maroc* 178: 1–287.

DUN, W. S., 1904. Notes on some new species of Palaeozoic Brachiopoda from New South Wales. *Records of the Geological Survey of New South Wales* 7: 318–325.

ERBEN, H. K., 1960. Primitive Ammonoidea aus dem Unterdevon Frankreichs und Deutschlands. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 110: 1–128.

ERBEN, H. K., 1962. Unterlagen zur diskussion der Unter/Mitteldevon-Grenze. In *Symposium-Band der 2. Internationalen Arbeitstagung über die Silur/Devon-Grenze und die stratigraphie des Silurs und des Devons (1960)* 315: 62–70.

ERBEN, H. K., 1964. Die Evolution der altesten Ammonoidea (Lieferung I). *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 120: 107–212.

ERBEN, H. K., 1965. Die Evolution der altesten Ammonoidea (Lieferung II). *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 122: 275–312.

FARRELL, J. R., 1992. The Garra Formation (Early Devonian: late Lochkovian) between Cumnock and Larras Lee, New South Wales, Australia: stratigraphic and structural setting, faunas and community sequence. *Palaeontographica Abt. A* 222: 1–41.

FICHNER, F. & Havlíček, V., 1978. Middle Devonian brachiopods from Čelechovice, Moravia. *Sborník geologických věd paleontologie* 21: 49–106.

FOERSTE, A. F., 1917. Notes on Silurian fossils from Ohio and other central states. *Ohio Journal of Science* 17: 233–268.

FÖLDVARY, G. Z., 2000. Siluro-Devonian invertebrate faunas from the Bogan Gate-Trundle-Mineral Hill area of central New South Wales. *Records of the Western Australian Museum, Supplement* 58: 81–102.

GEORGE, T. N., 1931. Ambocoelia Hall and certain similar British Spiriferidae. *Quarterly Journal of the Geological Society of London* 87: 30–61.

GILL, E. D., 1950. Preliminary account of the palaeontology and palaeoecology of the Eldon Group Formations of the Zeehan area, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 1949: 231–258.

GILL, E. D., 1951. Two new brachiopod genera from Devonian rocks in Victoria. *Memoirs of the National Museum, Melbourne* 17: 187–205.

GIRTY, G. H., 1904. New molluscan genera from the Carboniferous. *United States National Museum Proceedings* 27: 721–736.

GOLDFUSS, A., 1839. Beiträge zur Petrefactenkunde. *Verhandlgen der Kaiserlichen Leopoldinisch-Carolinischen der Naturforscher* 19: 327–364.

GRATSIANOVA, R. T., 1974. "Shukhertelly" rannego i srednego devona na yuge zapadnoi Sibiri: sistematicheskaia prinadle zhnost', elementy ekologii stratigraficheskoi znachenie. In *Sreda i zhizn' v geologicheskom proshlom (paleoekologicheskiye problemy), O. A. Betekhtina & I. T. Zhuravleva, eds Akademiia Nauk SSSR, Sibirskoe Otdelenie, Institut Geologii i Geofiziki (IGIG), Trudy* 84: 77–87.

GÜRICH, G., 1896. Das Paläeozoicum Polnischen Mittelgebirge. *Verhandlungen der Russisch-Kaiserliche Mineralogische Gesellschaft zu St. Petersbourg* 32: 1–539.

HALL, J., 1843. Survey of the fourth geological district. *Natural history of New York, Geology, vol.* 4. Carroll & Albany, Albany, ix+525 pp.

Hall, J., 1857. Descriptions of new species of Palaeozoic fossils from the Lower Helderberg, Oriskany Sandstone, Upper Helderberg, Hamilton and Chemung Groups. *New York State Cabinet of Natural History 10th Annual Report*: 41–186.

Hall, J., 1859a. Observations on genera of Brachiopoda. Contributions to the palaeontology of New York. *New York State Cabinet of Natural History 12th Annual Report* 8–110.

Hall, J., 1859b. Containing descriptions and figures of the organic remains of the Lower Helderberg Group and the Oriskany Sandstone. *Natural History of new York, Palaeontology* 3: 1–532.

Hall, J., 1860. Descriptions of new species of fossils, from the Hamilton group of western New York, with notices of others from the same horizon in Iowa and Indiana. *New York State Cabinet of Natural History 13th Annual Report* 76–94.

Hall, J., 1863. Contributions to palaeontology. *16th Annual Report of the Regents of the University of the State of New York on the condition of the State Cabinet of Natural History*: 3–226.

Hall, J. & Clarke, J. M., 1892. An introduction to the study of the genera of Palaeozoic Brachiopoda. *Palaeontology of New York* 8: 1–367.

Hall, J. & Clarke, J. M., 1893. An introduction to the study of the genera of Palaeozoic Brachiopoda. *Palaeontology of New York* 8: 1–317.

Hall, J. & Clarke, J. M., 1894. An introduction to the study of the Brachiopoda, intended as a handbook for the use of students. *Thirteenth Annual Report of the New York State Geologist for the Year 1893, Palaeontology* 2: 751–943.

Harper, C. W., 1973. Brachiopods of the Arisaig Group (Silurian-Lower Devonian) of Nova Scotia. *Geological Survey of Canada Bulletin* 215: 1–163.

Harper, C. W. & Boucot, A. J., 1978a. The Stropheodontacea, part I: Leptostrophiidae, Eostropheodontidae and Strophonellidae. *Palaeontographica Abt. A* 161: 55–118.

Harper, C. W. & Boucot, A. J., 1978b. The Strophomenacea, part II: Douvillinidae, Telaeoshaleriidae, Amphistrophiidae and Shaleriidae. *Palaeontographica Abt. A* 161: 119–175.

Harper, C. W., Johnson, J. G. & Boucot, A. J., 1967. The Pholidostrophinae (Brachiopoda; Ordovician, Silurian, Devonian). *Senckenbergiana lethaea* 48: 403–461.

Harper, D. A. T., 2000. Dalmanellidina. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 3: Linguliformea, Craniiformea, and Rhynchonelliformea (part)*. R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 782–844.

Havlíček, V., 1953. O několika nových ramenonožcích českého a moravského středního devonu. *Věstník Ústředního ústavu geologického* 28: 4–9.

Havlíček, V., 1956. Ramenonozci vapencu branickych a hlubocepskych z nejblizsiho prazskeho okoli. *Sborník Ústředního ústavu geologického* 22: 535–665.

Havlíček, V., 1959a. Rhynchonelloidea des böhmischen älteren Paläozoikums (Brachiopoda). Rozpravy *Ústředního ústavu geologického* 27: 1–211.

Havlíček, V., 1959b. Spiriferidae v českém siluru a devonu (Brachiopoda). *Rozpravy Ústředního ústavu geologického* 25: 1–219.

Havlíček, V., 1967. Brachiopoda of the suborder Strophomenidina in Czechoslovakia. *Rozpravy Ústředního ústavu geologického* 33: 1–235.

Havlíček, V., 1975. New genera and species of Orthida (Brachiopoda). *Věstník Ústředního ústavu geologického* 50: 231–235.

Havlíček, V., 1977. Brachiopods of the order Orthida in Czechoslovakia. *Rozpravy Ústředního ústavu geologického* 44: 1–327.

Hill, D., 1950. Middle Devonian corals from the Buchan district, Victoria. *Proceedings of the Royal Society of Victoria* 62: 137–164.

Hill, D., Playford, G. & Woods, J. T., 1967. *Devonian Fossils of Queensland*. Queensland Palaeontographical Society, Brisbane, 32 pp.

Holloway, D. J., 1996. New Early Devonian styginid trilobites from Victoria, Australia, with revision of some spinose styginids. *Journal of Paleontology* 70: 428–438.

Holmer, L. E. & Popov, L. E. 2000. Lingulata. In *Treatise on Invertebrate Paleontology,*

part H, Brachiopoda, revised, volume 2: Linguliformea, Craniiformea, and Rhynchonelliformea (part), R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 30–146.

Hou Hong-Fei & Xian Si-Yuan, 1975. The Lower and Middle Devonian brachiopods from Guangxi and Guizhou. *Professional Papers of Stratigraphy and Palaeontology* 1: 1–85.

House, M. R., 1979. Biostratigraphy of the early Ammonoidea. In The Devonian System, M. R. House, C. T. Scrutton & M. G. Bassett, eds. *Special Papers in Palaeontology* 23: 263–280.

Howitt, A. W., 1876. Notes on the Devonian rocks of northern Gippsland. *Geological Survey of Victoria, Progress Report* 3: 181–249.

ICZN, 1956. Opinion 420. Addition to the "Official List of Specific Names in Zoology" of the specific names for eleven species of the Class Brachiopoda and for 2 species of the Class Cephalopoda originally published by Martin (W.) in 1809 in the nomenclatorially invalid work entitled "Petrificata Derbiensia" and now available as from the first subsequent date on which they were severally published in conditions satisfying the requirements of the "Regles". *Opinions and Declarations Rendered by the International Commission on Zoological Nomenclature* 14: 131–167.

Johnson, J. G., 1970a. Great Basin Lower Devonian Brachiopoda. *Memoir of the Geological Society of America* 121: 1–421.

Johnson, J. G., 1970b. Early Middle Devonian brachiopods from central Nevada. *Journal of Paleontology* 44: 252–264.

Johnson, J. G., 1971. Some new and problematical brachiopods from the Lower Devonian of Nevada. *Journal of Paleontology* 45: 95–99.

Johnson, J. G., 1974a. Middle Devonian Givetian brachiopods from the *Leiorhynchus castanea* Zone of Nevada. *Geologica et Palaeontologica* 8: 49–96.

Johnson, J. G., 1974b. Affinity of Dayiacean brachiopods. *Palaeontology* 17: 437–439.

Johnson, J. G. & Boucot, A. J., 1968. External morphology of Anatrypa (Devonian, Brachiopoda). *Journal of Paleontology* 42: 1205–1207.

Johnson, J. G., Boucot, A. J. & Murphy, M. A., 1973. Pridolian and Early Gedinnian age brachiopods from the Roberts Mountains Formation of Central Nevada. *University of California Publications in Geological Science* 100: 1–75.

Johnson, J. G. & Talent, J. A., 1967. *Muriferella*, a new genus of Lower Devonian septate Dalmanellid. *Proceedings of the Royal Society of Victoria* 80: 43–50.

Johnston, P. A., 1993. Lower Devonian Pelecypoda from southeastern Australia. *Memoirs of the Association of Australasian Palaeontologists* 14: 1–134.

Kaesler, R. L. ed., 2000. *Treatise on Invertebrate Palaeontology, part H, Brachiopoda, revised, volumes 2–3: Linguliformea, Craniiformea, and Rhynchonelliformea (part)*. Geological Society of America and University of Kansas Press, Boulder and Lawrence, xxx+ii+919 pp.

Kaesler, R. L. ed., 2002. *Treatise on Invertebrate Palaeontology, Part H, Brachiopoda, revised, volume 4: Rhynchonelliformea (part)*. Geological Society of America and University of Kansas Press, Boulder and Lawrence, xxxix+767 pp.

Kaplun, L. I. & Krupchenko, N. V., 1991. Brakhipody nizhnego i srednego devona Dzhungaro-Balkhashskoi provintsii. In *Biostratigrafiia nizhnego i srednego devona Dzhungaro-Balkhashskoi provintsii*, V. N. Dubatolov & G. A. Stukalina, eds. Nauka, Novosibirsk, 111–147.

Kayser, E., 1871. Die Brachiopoden atus Mittel- und Ober-Devon der Eifel. *Zeitschrift der Deutschen Geologischen Gesellschaft* 23: 491–647.

Kozlowski, R., 1929. Les brachiopodes gothlandiens de la Podolie Polonaise. *Palaeontologica Polonica* 1: 1–254.

Kozlowski, R., 1946. *Howellella*, a new name for *Crispella* Kozlowski, 1929. *Journal of Paleontology* 20: 295.

Krause, F. F. & Rowell, A. J., 1975. Distribution and systematics of the inarticulate brachiopods of the Ordovician carbonate mud mound of Meiklejohn Peak, Nevada. *University of Kansas Paleontological Contributions Paper* 61: 1–74.

Lamarck, J. B. P., 1819. *Historie Naturelle des Animaux sans Vertèbres, part 1. Brachiopoda*. J. B. Baillière, Paris, 735 pp.

LENZ, A. C., 1977a. Upper Silurian and Lower Devonian brachiopods of Royal Creek, Yukon, Canada. Part 1: Orthoida, Strophomenida, Pentamerida, Rhynchonellida. *Palaeontographica Abt. A* 159: 37–109.

LENZ, A. C., 1977b. Upper Silurian and Lower Devonian brachiopods of Royal Creek, Yukon, Canada. Part 2: Spiriferida: Atrypacea, Dayiacea, Athyridacea, Spiriferacea. *Palaeontographica Abt. A* 159: 111–138.

LENZ, A. C. & JOHNSON, B. D., 1985a. Brachiopods of the Garra Formation (Lower Devonian), Wellington area, New South Wales, Australia: Orthida, Strophomenida, Pentamerida. *Palaeontographica Abt. A* 188: 35–70.

LENZ, A. C. & JOHNSON, B. D., 1985b. Brachiopods of the Garra Formation (Lower Devonian), Wellington area, New South Wales, Australia: Rhynchonellida, Spiriferida, Terebratulida. *Palaeontographica Abt. A* 188: 71–104.

LONG, J. A., 1984. New Placoderm fishes from the Early Devonian Buchan Group, eastern Victoria. *Proceedings of the Royal Society of Victoria* 96: 173–186.

LONG, J. A., 1986. New ischnacanthid acanthodians from the Early Devonian of Australia, with comments on acanthodian interrelationships. *Zoological Journal of the Linnean Society* 87: 321–339.

LUDVIGSEN, R., 1974. A new Devonian acrotretid (Brachiopoda, Inarticulata) with unique protegular ultrastructure. *Neues Jarbuch für Geologie und Paläontologie Monatschefte* 3: 133–148.

MAURER, F., 1889. Palaeontologische studien in gebeit des Rheinischen Devon. 8 Mitheilungen über fauna gliederung des Rechsrheinischen Unterdevon. *Neues Jahrbuch fur Mineralogie Abhandlungen* 2: 1–160.

MAWSON, R., 1987. Early Devonian conodont faunas from Buchan and Bindi, Victoria, Australia. *Palaeontology* 30: 251–297.

MAWSON, R. & TALENT, J. A., 1999. Early Devonian (Lochkovian) brachiopods from Windellama, southeastern Australia. *Senckenbergiana lethaea* 79: 145–189.

MAWSON, R. & TALENT, J. A., 2000. The Devonian of eastern Australia: stratigraphic alignments, stage and series boundaries, and the transgression-regression pattern re-considered. In Subcommission on Devonian stratigraphy: recognition of Devonian series and stage boundaries in geological areas, P. Bultynck, ed. *Courier Forschungsinstitut Senckenberg* 225: 243–270.

MAWSON, R., TALENT, J. A., BEAR, V. C., BENSON, D. S., BROCK, G. A., FARRELL, J. R., HYLAND, K. A., PYEMONT, B. D., SLOAN, T. R., SORENTINO, L., STEWART, M. I., TROTTER, J. A., WILSON, G. A. & SIMPSON, A. G., 1988. Conodont data in relation to resolution of stage and zonal boundaries for the Devonian of Australia. In Devonian of the world; proceedings of the second international symposium on the Devonian System; volume III, paleontology, paleoecology and biostratigraphy, N. J. McMillan, A. F. Embry & D. J. Glass, eds. *Memoir of the Canadian Society of Petroleum Geologists* 14: 485–527.

MAWSON, R., TALENT, J. A., BROCK, G. A. & ENGELBRETSEN, M. J., 1992. Conodont data in relation to sequences about the Pragian-Emsian boundary (Early Devonian) in southeastern Australia. *Proceedings of the Royal Society of Victoria* 104: 23–56.

MCCOY, F., 1867. On the recent zoology and palaeontology of Victoria. *Annals and Magazine of Natural History* 20: 175–202.

MCCOY, F., 1876. *Prodromus of the Palaeontology of Victoria* Decade 4: 15–20.

MERGL, M., 2001. Lingulate brachiopods of the Silurian and Devonian of the Barrandian (Bohemia, Czech Republic). *Acta Musei Nationalis Prague, Series B, Historia Naturalis* 57: 1–49.

MITCHELL, J. & DUN, W. S., 1920. The Atrypidae of New South Wales, with reference to those recorded from other states of Australia. *Proceedings of the Linnean Society of New South Wales* 45: 266–276.

MUIR-WOOD, H. M., 1925. Notes on the Silurian brachiopod genera *Delthyris*, *Uncinulina*, and *Meristina*. *Annals and Magazine of Natural History* 15: 83–95.

MUIR-WOOD, H. M., 1962. *On the morphology and classification of the brachiopod suborder Chonetoidea*. British Museum (Natural History), London, viii+132 pp.

MURCHISON, R. I., 1839. *The Silurian system founded on geological researches in the counties of Salop, Hereford, Radnor, Mongomery, Caerthmarthen, Brecon, Pembroke, Monmouth, Gloucester, Worcester, and Stafford: with descriptions of the coalfields and overlying formations.* John Murray Publishers, London, xxxiii+768 pp.

PAJCHLOWA, M. 1957. Dewon w profilu Grzegorzowice-Skaly. *Biuletyn Instytutu Geologicznego* 122: 145–254.

PARFREY, S. M., 1989. Early Devonian fossils from the Ukalunda Beds northwest of Mount Coolon, central Queensland. *Queensland Government Mining Journal* 90: 20–21.

PERRY, D. G., 1979. Late Early Devonian reef associated brachiopods of the Prongs Creek Formation, northern Yukon. *Journal of Paleontology* 53: 1094–1111.

PERRY, D. G., 1984. Brachiopoda and biostratigraphy of the Silurian-Devonian Delorme Formation in the district of Mackenzie, the Yukon. *Royal Ontario Museum Life Science Contributions* 138: 1–243.

PHILIP, G. M., 1962. The palaeontology and stratigraphy of the Siluro-Devonian sediments of the Tyers area, Gippsland, Victoria. *Proceedings of the Royal Society of Victoria* 75: 123–246.

PHILIP, G. M., 1966. Lower Devonian conodonts from the Buchan Group, eastern Victoria. *Micropaleontology* 12: 441–460.

PHILIP, G. M. & PEDDER, A. E. H., 1964. A re-assessment of the age of the Middle Devonian of south-eastern Australia. *Nature* 202: 1323–1324.

POPOV, L. E. 1981a. Pervaia nakhodka bezzamkovykh brakhiopod semeistva Acrotretidae v nizhnem devone SSSR. In *Paleontologicheskiia osnova stratigraficheskikh skhem paleozoia mezozoia ostrovo Sovetskoi Arktiki*, V. I. Bondarev, ed. Leningrad, 61–65.

POPOV, L. E. 1981b. Pervaia nakhodka mikroskopicheskikh bezzamkovykh brakhiopod semeistva Acrotretidae v silure Estonii. *Eesti NSV Teaduste Akadeemia Toimetised (Geologia)* 30: 34–41.

POPOV, L. E., NÕLVAK, J. & HOLMER, L. E., 1994. Late Ordovician lingulate brachiopods from Estonia. *Palaeontology* 37: 627–650.

PUSCH, G. G., 1833. *Geognostische Beschreibung von Polen, so wie der übregen Nordkarpathen-Länder. Part 1.* Stuttgart & Tübingen, 338 pp.

PYEMONT, B. D., 1990. *Conodont faunal succession through the Murrindal Limestone, Buchan area, Victoria.* MSc thesis, Macquarie University, Sydney (unpubl.).

QUENSTEDT, F. A., 1868–1871. Petrefactenkunde Deutschlands. *Die Brachiopoden* 2: 1–748.

RACHEBOEUF, P. R., 1987. Upper Lower and lower Middle Devonian chonetacean brachiopods from Bathurst, Devon and Ellesmere Islands, Canadian Arctic Archipelago. *Geological Survey of Canada Bulletin* 375: 1–29.

REED, F. R. C., 1908. The Devonian faunas of the northern Shan States. *Palaeontologica Indica* 2: 1–183.

RONG JIA-YU & COCKS, L. R. M., 1994. True Strophomena and a revision of the classification and evolution of strophomenoid and 'strophodontoid' brachiopods. *Palaeontology* 37: 651–694.

RZHONSNITSKAYA, M. A., 1975. Biostratigrafiia devona okrain Kuznetskogo basseina. Tom 2: Opisani brakhiopod, Chast' 1: Pentamerida i Atrypida. *Trudy Vsesoiuznyi Ordena Lenina Nauchno-issledovatel'skii Geologicheskii Institut* 244: 1–232.

SAVAGE, N. M., 1968. Planicardinia, a new septate dalmanellid brachiopod from the Devonian of New South Wales. *Palaeontology* 11: 627–632.

SAVAGE, N. M., 1969. New spiriferid brachiopods from the Lower Devonian of New South Wales. *Palaeontology* 12: 472–487.

SAVAGE, N. M., 1971. Brachiopods from the Lower Devonian Mandagery Park Formation, New South Wales. *Palaeontology* 14: 387–422.

SAVAGE, N. M., 1974. The brachiopods of the Lower Devonian Maradana Shale, New South Wales. *Palaeontographica Abt. A* 146: 1–51.

SAVAGE, N. M., 1981. A reassessment of the age of some Paleozoic brachiopods from southeastern Alaska. *Journal of Paleontology* 55: 353–369.

SCHINDEWOLF, O. H., 1932. Zur Stammesgeschichte der Ammoneen. *Paläontologische Zeitschrift* 14: 164–181.

SCHNUR, J. 1853. Zusammenstellung und Beschreibung sämmtlicher im Übergangsgebirge der Eifel vorkommenden Brachiopoden, nebest Abbildungen Derselben. *Palaeontographica* 3: 169–257.

SCHUCHERT, C. & COOPER, G. A., 1931. Synopsis of the brachiopod genera of the suborders Orthoidea and Pentameroidea, with notes on the Telotremata. *American Journal of Science (Series 5)* 22: 214–255.

SCHUCHERT, C. & COOPER, G. A., 1932. Brachiopod genera of the suborders Orthoidea and Pentameroidea. *Memoirs of the Peabody Museum of Natural History* 4: 1–270.

SELWYN, A. R. C. & ULRICH, G. H. F., 1867. Notes on the physical geography, geology and mineralogy of Victoria. *Intercolonial Exhibition of Australasia, Melbourne 1866–67* 3: 147–235.

SHERWIN, L., 1995. Siluro-Devonian brachiopods from the Amphitheatre and Winduck Groups (Cobar Supergroup), western New South Wales. *Memoirs of the Association of Australasian Palaeontologists* 18: 61–96.

SMITH, R. E., 1980. Lower Devonian (Lochkovian) biostratigraphy and brachiopod faunas, Canadian Arctic Islands. *Geological Survey of Canada Bulletin* 308: 1–155.

SOJA, C. M., 1988. Lower Devonian (Emsian) brachiopods from southeastern Alaska, U.S.A. *Palaeontographica Abt. A* 201: 129–193.

SOWERBY, J., 1822. *The mineral conchology of Great Britain, vol.* 4. Published by the author, London, 114 pp.

SPRIESTERSBACK, J. & FUCHS, A., 1909. Die fauna der Remscheider Schichten. *Abhandlungen Preussischen Geologischen Landesanstalt* 58: 1–81.

STRUSZ, D. L., 1982. Wenlock brachiopods from Canberra, Australia. *Alcheringa* 6: 105–142.

STRUSZ, D. L., 1990. Catalogue of type, figured and cited specimens in the Commonwealth palaeontological collection: Brachiopoda. *Bureau of Mineral Resources, Geology and Geophysics Report* 298: 1–289.

STRUSZ, D. L., 2000. Revision of the Silurian and Early Devonian chonetoidean brachiopods of southeastern Australia. *Records of the Australian Museum* 52: 245–287.

STRUSZ, D. L., CHATTERTON, B. D. E. & FLOOD, P. G., 1970. Revision of the New South Wales Devonian Brachiopod '*Spirifer*' *yassensis*. *Proceedings of the Linnean Society of New South Wales* 95: 170–190.

SUSSMILCH, C. A., 1914. *An Introduction to the Geology of New South Wales*, 2nd edn. Angus & Robertson, Sydney, 296 pp.

SUSSMILCH, C. A., 1922. *An Introduction to the Geology of New South Wales*, 3rd edn. Angus & Robertson, Sydney, 296 pp.

TALENT, J. A., 1956a. Devonian brachiopods and pelecypods of the Buchan Caves Limestone, Victoria. *Proceedings of the Royal Society of Victoria* 68: 1–56.

TALENT, J. A., 1956b. Siluro-Devonian brachiopods from Marble Creek, Thompson River, Victoria. *Proceedings of the Royal Society of Victoria* 68: 73–84.

TALENT, J. A., 1963. The Devonian of the Mitchell and Wentworth Rivers. *Memoirs of the Geological Survey of Victoria* 24: 1–118.

TALENT, J. A., 1965a. The stratigraphic and diastrophic evolution of central and eastern Victoria in Middle Palaeozoic times. *Proceedings of the Royal Society of Victoria* 79: 175–195.

TALENT, J. A., 1965b. The Silurian and Early Devonian faunas of the Heathcote District, Victoria. *Memoirs of the Geological Survey of Victoria* 26: 1–55.

TALENT, J. A., 1969. The geology of east Gippsland. *Proceedings of the Royal Society of Victoria* 82: 37–60.

TALENT, J. A., GRATSIANOVA, R. T. & YOLKIN, E. A., 2001. Latest Silurian (Pridoli) to Middle Devonian of the Asia-Australia hemisphere: rationalization of brachiopod taxa and faunal lists; correlation charts. *Courier Forschungsinstitut Senckenberg* 236: 1–221.

TALENT, J. A., MAWSON, R., AITCHISON, J. C., BECKER, R. T., BELL, K. N., BRADSHAW, M. A., BURROW, C. J., COOK, A. G., DARGAN, G. M., DOUGLAS, J. G., EDGECOMBE, G. D., FEIST, M., JONES, P. J., LONG, J. A., PHILLIPS-ROSS, J. R., PICKETT, J. W., PLAYFORD, G., RICKARDS, R. B., WEBBY, B. D., WINCHESTER-SEETO, T., WRIGHT, A. J., YOUNG, G. C. & ZHEN YONG-YI, 2000. Devonian palaeobiogeography of Australia and adjoining regions. In Palaeobio-

geography of Australasian faunas and floras, A. J. Wright, G. C. Young, J. A. Talent & J. R. Laurie, eds. *Memoir of the Association of Australasian Palaeontologists* 23: 167–257.

Teichert, C., 1948. Middle Devonian goniatites from the Buchan district, Victoria. *Journal of Paleontology* 22: 60–67.

Teichert, C. & Talent, J. A., 1958. Geology of the Buchan area, east Gippsland. *Memoirs of the Geological Survey of Victoria* 21: 1–52.

Tien, C. C., 1938. Devonian Brachiopoda of Hunan. *Palaeontologia Sinica* 4: 1–192.

Valentine, J. L., Brock, G. A. & Molloy, P. D., 2003. Linguliformean brachiopod faunal turnover across the Ireviken Event (Silurian) at Boree Creek, central-western New South Wales, Australia. *Courier Forschungsinstitut Senckenberg* 242: 301–327.

Vandercammen, A., 1963. Spiriferidae du Dévonien de la Belgique. *Institut Royal des Sciences Naturelles de Belgique, Mémoires* 150: 1–179.

Veevers, J. J., 1959. Devonian brachiopods from the Fitzroy Basin, Western Australia. *Bureau of Mineral Resources, Geology and Geophysics Bulletin* 45: 1–220.

Von Bitter, P. H. & Ludvigsen, R., 1979. Formation and function of protegular pitting in some North American acrotretid brachiopods. *Palaeontology* 22: 705–720.

Von Meyer, H., 1831. Beschreibung des *Orthoceratites striolatus* und über den bau und das Vorkommen einiger vielkammeriger fossiler Cephalopoden, nebst Beschreibung von *Calymene aequalis. Vernhandlungen der Leopoldinisch-Carolinisch Akademie der Naturforschende* 15: 59–112.

Walcott. C. D., 1884. Paleontology of the Eureka District. *United States Geological Survey Monographs* 8: 1–298.

Wallace, M., 1987. The role of internal erosion and sedimentation in the formation of stromotactis mudmounds and associated lithologies. *Journal of Sedimentary Petrology* 57: 695–700.

Walmsley, V. G. & Boucot, A. J., 1971. The Resserellinae-a new subfamily of Late Ordovician to Devonian dalmanellid brachiopods. *Palaeontology* 14: 487–531.

Walmsley, V. G. & Boucot, A. J., 1975. The phylogeny, taxonomy and biogeography of Silurian and Early to mid-Devonian Isorthinae (Brachiopoda). *Palaeontographica Abt. A* 148: 34–108.

Wang Yü, 1956. Some new brachiopods from the Yükiang Formation of Southern Kwangsi Province. *Scientia Sinica* 5: 373–388.

Wang Yü & Rong Jia-Yu, 1986. Early Emsian (Devonian) brachiopods of the Nanning-Liujing district, central Guangxi, southern China. *Palaeontologia Sinica* 172: 1–282.

Wang Yü, Rong Jia-Yu & Chen Xiu-Qin, 1987. Early late Emsian brachiopods from Dale, Xiangzhou, Guangxi. *Memoirs of the Nanjing Institute of Geology and Palaeontology* 23: 121–146.

Wang Yü, Yü Chang-Ming & Wu Qi, 1974. Advances in the Devonian biostratigraphy of south China. *Memoirs of the Nanjing Institute of Geology and Palaeontology* 6: 1–71.

Webby, B. D., Stearn, C. W. & Zhen Yong-Yi, 1993. Lower Devonian (Pragian-Emsian) stromatoporoids from Victoria. *Proceedings of the Royal Society of Victoria* 105: 113–185.

Whitehouse, F. W., 1929. Preliminary report on Devonian fossils from the districts of Mt Wyatt and Ukalunda. *Queensland Government Mining Journal* 30: 158–159.

Williams, A. & Brunton, C. H., 1993. Role of shell structure in the classification of the orthotetidine brachiopods. *Palaeontology* 36: 931–966.

Williams, A. & Harper, D. A. T., 2000. Orthida. In *Treatise on Invertebrate Paleontology, part H, Brachiopoda, revised, volume 3: Linguliformea, Craniiformea, and Rhynchonelliformea (part)*, R. L. Kaesler, ed. Geological Society of America and University of Kansas Press, Boulder and Lawrence, 714–844.

Winchester-Seeto, T. M., 1996. Emsian Chitinozoa from the Buchan area of southeastern Australia. *Acta Palaeontologica Polonica* 41: 149–230.

Winchester-Seeto, T. M. & Paris, F., 1989. Preliminary investigations of some Devonian (Lochkovian-Eifelian) chitinozoans from eastern Australia. *Alcheringa* 13: 167–173.

Xu Han-Kui, 1987. Lower Devonian brachiopods from Xainza, northern Xizang. *Bulletin of the Nanjing Institute of Geology and Palaeontology* 11: 21–62.

Zhang Ning, 1989. Wenlockian (Silurian) brachiopods of the Cape Phillips Formation, Baillie Hamilton Island, Arctic Canada: part 1. *Palaeontographica Abt. A* 206: 49–97.

CONODONTS FROM THE WOMBAT CREEK GROUP AND "WIBENDUCK LIMESTONE" (SILURIAN) OF EASTERN VICTORIA

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Conodonts from four carbonate occurrences in the Wombat Creek Group — of the Wombat Creek Graben — a unit closely associated with the "type locality" of the inferred Benambran Orogeny, demonstrate that it includes horizons at least as old as *celloni* Zone (Early Silurian, late Llandovery, Telychian) as well as latest Silurian (Přidolí). Two and possibly three of the most prominent Wombat Creek Group limestones align chronologically with two of the oldest carbonate intervals of the Enano Group (of the Limestone Creek Half-graben) farther east in Victoria, specifically the Lobelia and Farquhar limestones. They also align chronologically with portion of the McCarty's limestone on the right flank of the Indi (= upper Murray) River in southeast New South Wales. The last of these documents carbonate sedimentation commencing earlier, in the early Llandovery (Rhuddanian). The youngest of the four Wombat Creek Group carbonate occurrences to have produced conodonts, Pyle's limestone deposit, is tectonically problematic, but its age is Přidolí (latest Silurian). The Wombat Creek Group and Enano Group sedimentation (and flanking "lost" carbonate platform accumulations) thus appear to have extended through most of Silurian time, from Llandovery to somewhere close to the Silurian–Devonian boundary. The Silurian sedimentary packages of the Wombat Creek Graben and Limestone Creek Half-graben have been regarded as developmentally discrete, but salient similarities in depositional sequence and in chronologic alignments are consistent with them being now-disjunct portions of a formerly continuous sedimentary accumulation, i.e. their preservation in separate tracts may be an artifact of post-depositional tectonics.

Conodont data from an isolated occurrence, the "Wibenduck Limestone", indicate probable mid-Ludlow age (probable latest Gorstian to earliest Ludfordian). It consists of limestone clasts and olistoliths and possibly equates with submarine fans of Lochkovian age elsewhere, such as the Sharpeningstone Conglomerate of the Yass area, southern New South Wales.

Keywords: Victoria, Silurian, Wombat Creek Group, Enano Group, "Wibenduck Limestone", conodonts, Benambran Orogeny

LIMESTONES, long regarded as Late Silurian in age, occur at many horizons in the Wombat Creek Group, a unit outcropping in the valley of the Mitta Mitta River and adjacent parts of the watersheds of the Gibbo River and of the Wombat and Morass Creeks of eastern Victoria (Stirling 1887, 1888b; Ferguson 1899; Chapman 1912; Thomas 1954; Whitelaw 1954; Talent 1959; Bolger 1982; VandenBerg et al. 1998a, 2000). Rocks of broadly similar age, known as the Enano Group, outcrop in the watersheds of the Indi, upper Buchan and upper Tambo rivers about 40–50 km farther east (Whitelaw 1954; VandenBerg et al. 1984; Allen 1987, 1988, 1991, 1992; Simpson & Talent 1995, 1996; Talent et al. 2003a) — for broad location see lower part of Fig. 1. It has been demonstrated (Simpson & Talent 1995) that the age-spectrum represented by the limestones and other calcareous sediments of the Enano Group equate with most of Silurian time — Llandovery (Aeronian and possibly late Rhuddanian) to Přídolí. Despite the abundance of limestone bodies in the Wombat Creek Group, no compelling data have been presented as to the age-spectrum represented by carbonate bodies and calcareous intervals of the latter. In this report, we provide conodont data bearing on this lacuna.

Opinions diverge regarding the environments of deposition of the Wombat Creek and Enano Groups, some authors regarding all carbonate bodies and calcareous intervals to be allochthonous (VandenBerg et al., 2000), others (principally ourselves) opining that both allochthonous and essentially autochthonous carbonate occurrences are represented. Regardless of the viewpoint advocated, it should be emphasised that most exposures of carbonate bodies and calcareous intervals in both regions are poor,

leading to uncertainty regarding relationships to nearby non-calcareous sediments of most but not all limestone occurrences.

The "Wibenduck Limestone", previously regarded as autochthonous (VandenBerg 1988; VandenBerg et al. 1992, 2000), is regarded as consisting of clasts and olistoliths of various carbonate lithologies, lithified before cannibalisation and subsequent deposition at the top of the Sardine Conglomerate fan deposit; its continued use as a discrete formation is not recommended. A probable latest Gorstian–earliest Ludfordian age is indicated for the "Wibenduck Limestone" materials (see below).

The age-span represented by the Wombat Creek Group has special relevance as regards the Benambran Orogeny as it occurs in what may be termed the "type area" for the latter (Andrews 1938; Browne 1947). But the previously available poor age-constraints on the Wombat Creek Group and, by extension, the onset of the Benambran orogenic event (or events) in that area has led some authors to propose that it is a senior synonym of the "Quidongan Orogeny" (Crook et al. 1973; Ramsay & VandenBerg 1986), an event based, incidentally, on a very local and arguably regionally insignificant unconformity (authors' observations) within the Silurian sequence at Quidong in southeastern New South Wales. The latter unconformity occurs between the Merriangah Siltstone (age determined by graptolites as lying between the late Llandovery *Monograptus crenulatus* and *M. crispus* zones), a distal flysch sequence, and the overlying Quidong Limestone. The precise time-slice within the Wenlock–Ludlow represented by the Quidong Limestone is presently under investigation by R. Parkes (pers. comm.). Of greater sedimentary-tectonic significance at Quidong, in our view, is the Tombong Beds — a thick proximal flysch sequence — resting with profound unconformity on the Late Ordovician Bombala Beds and passing upwards with decrease in arenites into the aforementioned late Llandovery Merriangah Siltstone.

Our observations at Quidong, we emphasise, do not preclude age- and sedimentary-tectonic inferences from unconformities and patterns of sedimentation in Llandovery–Wenlock sequences elsewhere in eastern Australia, but need to be taken into account in evaluating data bearing on "Benambran events" throughout eastern Australia, including resolving questions of diachronism — for which presently available data are far from adequate.

The question of the ages and allochthoneity or otherwise of the limestone bodies in the Mitta Mitta River–Gibbo River–Wombat Creek region (VandenBerg 1998a; VandenBerg et al. 2000) is relevant with regard to dating associated strata and for inferences regarding the time-span to be accorded the Benambran orogenic cycle/cycles in this, its "type locality". Accordingly, before and after filling of the Dartmouth Dam, we extensively sampled most of the major occurrences of limestones in the Wombat Creek Group, and undertook additional sampling of limestones in the Enano Group of the Limestone Creek Half-graben — in quest of data additional to what we presented earlier for the Enano Group (Simpson & Talent 1995) — as well as sampling of the "Wibenduck Limestone".

Below we present conodont data from three limestone occurrences in the Mitta Mitta River–Gibbo River–Wombat Creek area (numbered 1–3 on Fig. 2;), from the small occurrence known as Pyle's limestone deposit near Benambra, and from the "Wibenduck Limestone" farther east (Fig. 1 and 2; see Appendix for locality data), and discuss the age and environmental significance of these occurrences.

CONODONT FAUNAS AND AGES

1. "Lower Mitta" limestone (Loc. 1 — see Appendix)

Low diversity but chronologically interesting faunas were obtained from the "Lower Mitta" limestone on the right flank of the Mitta Mitta River (Table 1). *Ozarkodina cadiaensis* has been reported previously from only three locations in southeastern Australia. These are an unnamed subsurface limestone in the Cadia Mine area about 20 km southwest of Orange (PC 402 of Bischoff 1986; see also Packham et al. 1999), low in the Boree Creek Formation (B5 of Bischoff 1986) and the Lobelia limestone lens adjacent to the Reedy Creek Fault in eastern Victoria (Simpson & Talent 1995: fig. 4). From the associated fauna of PC 402, Bischoff argued that *O. cadiaensis* was restricted to the latest Llandovery to earliest Wenlock *amorphognathoides* Zone. Simpson & Talent (1995: 93) in discussing the age of the Lobelia limestone lens argued that the lower range of the taxon could possibly be construed as of *celloni* Zone age. This was based on unillustrated associated faunas low in the Boree Creek Formation

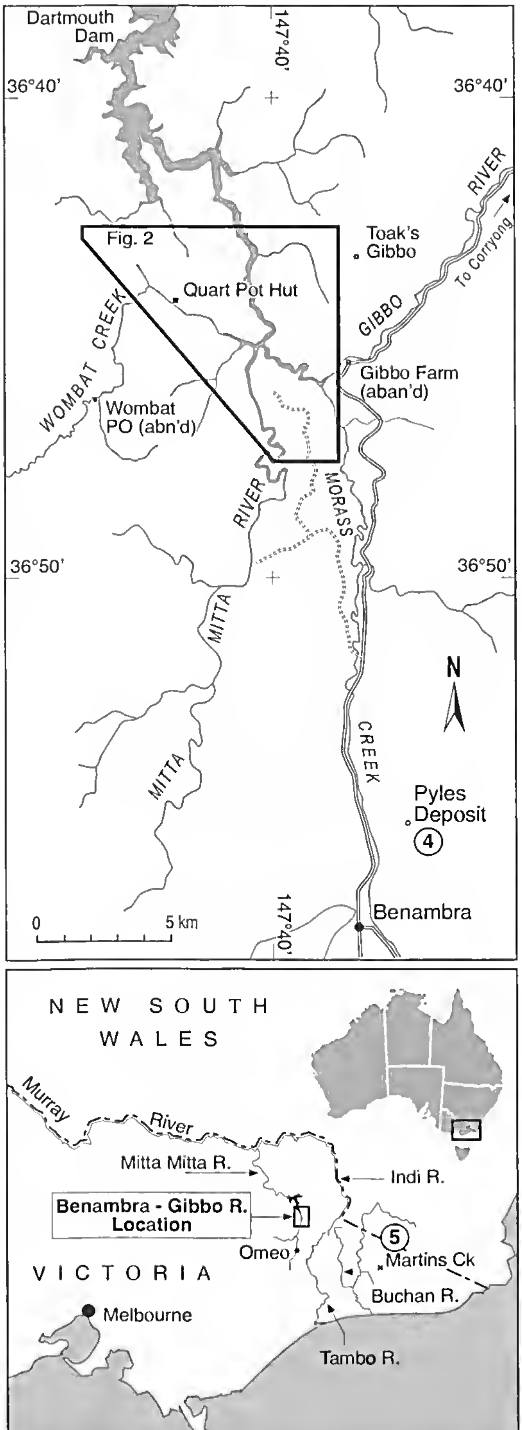


Fig. 1. Location of Fig. 2, and location of Mitta Mitta River-Gibbo River-Wombat Creek region in relation to eastern Victoria.

tabulated by Bischoff (1986) as *Pterospathodus amorphognathoides* that could possibly be interpreted as pennate forms of *Pterospathodus celloni sensu* Männik & Aldridge (1989; see also Männik 1998). New data from the Boree Creek Formation of east-central New South Wales are likely to shed further light on the lower limit of the *amorphognathoides* Zone in this unit (Molloy in prep.), but from published data it is reasonable to construe the range of *O. cadiaensis* as broadly late Llandovery to earliest Wenlock *celloni* and *amorphognathoides* zones. The taxon, incidentally, was noticeably absent in a recent report on the fauna of an *amorphognathoides* Zone carbonate unit in the Cadia region (Rickards et al. 2001). Simpson & Talent (1995: 142) have noted that this taxon appears to be ecologically constrained.

The occurrence of Pa elements of *Ozarkodina australensis*, an Sc element of the genus *Distomodus* herein interpreted as *D. staurognathoides*, and the coniform *Panderodus* taxa generally accord with a *celloni* to *amorphognathoides* zone age for the "Lower Mitta" limestone. This unit can therefore be correlated with the upper parts of the lower Claire Creek limestone unit, the upper parts of the McCarty's limestone and it can be broadly correlated with both the Lobelia and Farquar limestones in the Limestone Creek region (Simpson & Talent 1995).

2. Brammall Bluff, Gibbo River (Loc. 2 — see Appendix)

The small conodont fauna recovered from this unit includes elements of the ubiquitous Early Silurian taxon *Distomodus staurognathoides* and the more chronologically restricted *Ozarkodina cadiaensis*. A late Llandovery to earliest Wenlock *celloni* and *amorphognathoides* zones age-range, broadly equivalent with the "Lower Mitta" limestone discussed above, is therefore indicated. A single element of the coniform taxon *Pseudobelodella silurica* was also recovered. Armstrong (1990: 111) records *P. silurica* from the Lafayette Bugt Formation of Greenland and suggests this monospecific genus is restricted to the upper *celloni* and *amorphognathoides* zones. This unit can therefore also be correlated with the upper parts of the lower Claire Creek limestone unit, the upper parts of the McCarty's limestone and broadly correlated with both the Lobelia and Farquar limestones (Simpson & Talent 1995).

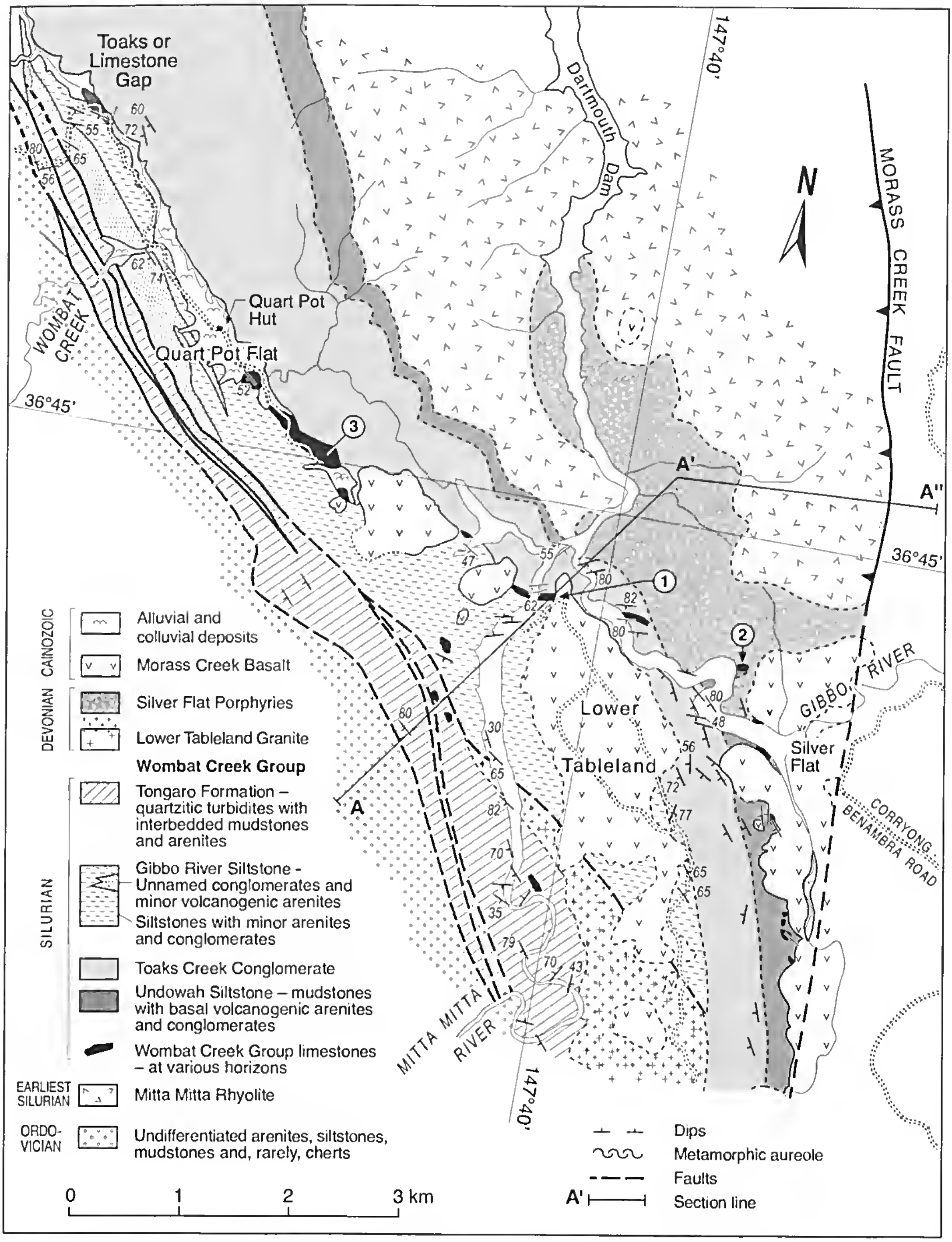


Fig. 2. Geology of Mitta Mitta River-Gibbo River-Wombat Creek region based on VandenBerg et al. (1998b). Localities 1, 2 and 3 refer to localities producing conodonts documented in his report — for details see appendix.

			Distamodus staurognathoides		*Ozarkodina australensis*				*Ozarkodina cadiaensis*						*Ozarkodina aff. cadiaensis*			*Ozarkodina excavata excavata*					*Ozarkodina martinssoni auriformis*	*Ozarkodina remsch. eosteinhornensis*	*Panderodus ? greenlandensis*	*Panderodus recurvatus*	*Panderodus ? n.sp.*	*Panderodus unicostatus*	*Panderodus sp.*	*Pseudobelodella silurica*	*Ozarkodina sp.*	*? Icriodus sp. A*	Totals
	SAMPLE	CAI	Pb		Pa	Pb	Sb	Sc	Pa	Pb	M	Sa	Sb	Sc	Pa	Pb	Sa	Pa	Pb	Sa	Sb	Sc	Pa	Pa							Sb	Sb	
1. "Lower Mitta ls."	0.0m																												1				1
	3.2m	6			6	2		1	2	1																		13	14				39
	4.9m	6																											1				1
	13.5m																									1		2	3				6
	14.5m																											4	3				7
	15.6m				2		1		1	2	2	1	1															4	5				19
	15,7m	6 - 6.5							3	2		1		1														11	5				23
	17.1m									1																		1	1				3
	18.3m					1																											1
	19.3m	·	1		1													1				2			1			1	7				14
	20.5m	6		1	1			1						1				2	1		1	2				3		9	13				35
	22.5m	6	1						8	5															5	1		19	22				61
	23.0m	6					1		1									1										3	5				11
	23.5m																											7	5				12
	27.4m	6							1	1		1						1				1			2	1		8	6				22
2.Brammall Bluff	0.1m	4.5 - 5	2	1					2	1	1																	1				8	
	5.7m			1																						1			4	1			7
	11.2m																												2				2
	16.7m																					1				1							2
	67.0m	4.5 - 5																										1	3				4
3. Quart Pot SE		6.5 - 8													1	1	1																3
4. Pyles deposit		8																			1			1			1		2		1		6
5. "Wibenduck Ls."		5.5 - 6																	1	1		1	1									1	5
Totals			4	3	10	3	2	2	18	13	3	3	1	2	1	1	1	5	2	1	2	7	1	1	7	8	1	85	102	1	1	1	292

Table 1. Distribution and colour alteration indices (CAI values) of conodonts from samples from measured sections through the "Lower Mitta" and Brammall Bluff ("Hairpin") limestones, Gibbo R., and from spot samples from the Quart Pot and Pyle's limestones and the "Wibenduck Limestone". In the case of the Brammall Bluff section, the sampled section commenced 75 m upstream from the base of the carbonate-bearing sequence.

3. Quart Pot limestone (Loc. 3 — see Appendix)

Only four conodont elements were recovered from this unit. They are herein identified as elements of *Ozarkodina* aff. *cadiaensis*. It is therefore impossible to ascribe a reasonably accurate age for the deposition of this unit on available data. Given the stratigraphic context, however, a broad Early Silurian age is inferred.

4. Pyle's limestone deposit (loc. 4 — see Appendix)

Previous undocumented identifications of conodonts (Bischoff in Talent et al. 1975) implied the fauna is Přídolí or possibly Lochkovian in age (Simpson & Talent 1995: 82). This interpretation was based on a small number of form element taxa that could be interpreted as elements of *Ozarkodina remscheidensis* (Simpson & Talent 1995: 82). The identification in this study of a single Pa element as the subspecies *O. remscheidensis eosteinhornensis* restricts the age of the Pyle's deposit to the Silurian (latest Ludlow to mid Přídolí). This unit can be broadly correlated with the Native Dog limestone unit in the Limestone Creek region (Simpson & Talent 1995).

5. "Wibenduck Limestone" (Loc. 5 — see Appendix)

Conodonts reported but not documented from the "Winbenduck Limestone" (VandenBerg 1988: 131) were *Kockelella variabilis*, *K. ranuliformis*, *Ozarkodina confluens*, *O. excavata*, *Belodella anomalis*, and *Coryssognathus dubius* (recorded as *Pelekysgnathus dubius*). It has already been pointed out (Simpson 1995; Talent et al. 2003a) that *Kockelella ranuliformis* suggests a generalized Wenlock age, but may extend into the *Polygnathoides siluricus* Zone of the lower part of the upper Ludlow. *Kockelella variabilis* suggests *Ancoradella ploeckensis* and *Polygnathoides siluricus* zones, and *C. dubius* suggests the Ludlow. The fauna was thus thought to imply a generalized Ludlow age for the "Wibenduck Limestone" (Talent et al. 2003a). Lennart Jeppsson (pers. comm. 2003) has pointed out that on Gotland this association is restricted to a brief interval somewhere in the latest Gorstian–earliest Ludfordian.

It should be noted that none of the conodonts listed above have been examined by the authors. In this study only a small number of recognisable conodonts were recovered. These were elements of *Ozarkodina excavata excavata*, a single Pa element of *Ozarkodina martinssoni auriformis*, and a Pb element of *Icriodus* sp.

O. martinssoni auriformis has been obtained from the Coral Gardens Formation of the Jack Group in the Broken River region (Simpson 2000, 2003). The taxon is interpreted as ranging from the Ludlow *siluricus* Zone to the latest Přídolí to Early Devonian *woschmidti* zone. Simpson (1998) reported the recovery of icriodontid elements from the top of the *siluricus* Zone from two localities in the Broken River region.

On available data, the "now lost" source of this allochthonous material correlates broadly with the autochonous sequences spanning the upper parts of the upper Claire Creek limestone unit and interbedded carbonates and clastics directly overlying this unit in the Limestone Creek region (headwaters of the Indi River) (Simpson & Talent 1995). Because this fauna is from clasts of various lithologies, additional sampling could well produce minor chronological incongruities.

Conodont Colour Alteration Indices (CAI)

Determinations of CAI of the conodonts from this study (Table 1) have been made using a colour standard set of conodonts — of various shape, size and robustness — made available to us by Dr Anita Harris of the U.S. Geological Survey, thus obviating problems which might have arisen from inaccuracies in published colour illustrations (Epstein et al. 1977; Harris 1979 1981; Rejebian et al. 1987), or apparent differences in colour occasioned by relative robustness or delicacy of individual elements for which CAI values were being estimated.

Conodonts from four of the five localities investigated fall in the range of CAI 5.5–6 (Table 1), not very much above the overall average of 4.5–5.5 encountered over much of the Lachlan Foldbelt of eastern Australia for most Ordovician, Silurian and Devonian (early Givetian and older) platform sequences (Brime et al. 2003; Mawson & Talent unpub. data). Because the sequence at Bammall Bluff (loc. 2) had been reported to include skarn associated with felspar-quartz porphyry (VandenBerg et al. 1998a: 204), we anticipated that conodonts from this occurrence were likely to have high CAI values indicative of temperatures associated with skarns found adjacent to plutons (cf. Meinert 1992). Fluid inclusions, however, indicate prevailing

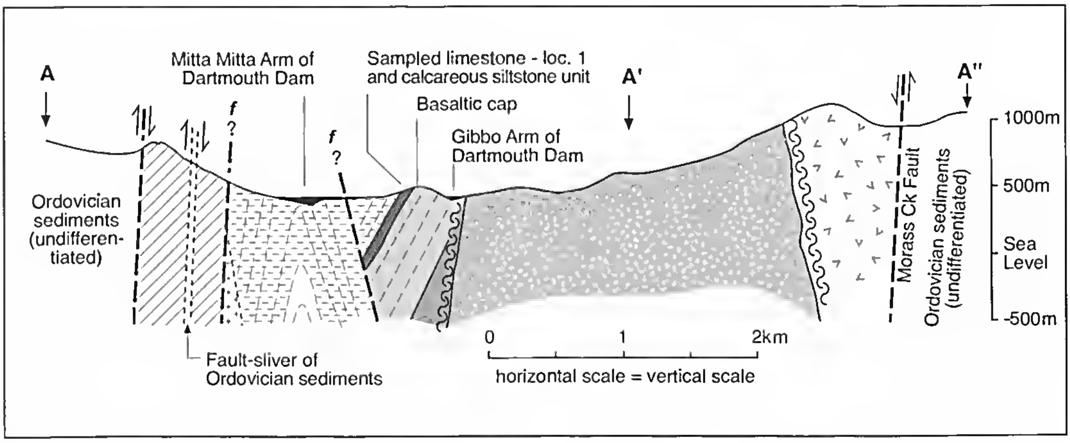


Fig. 3. Cross-section A-A'-A" of Mitta Mitta River-Gibbo River-Wombat Creek region (for location see Fig. 2).

temperatures of formation of skarns in the range 300–700°C, but with occasional lower and much higher temperatures. The CAI values of conodonts from the Brammall Bluff sequence (loc. 2) are 4.5–5. This equates with about 250–350°C for 1–10 Ma of annealing (cf. Epstein et al. 1977; Harris 1979, 1981; Rejebian et al. 1987) — towards the lower end of temperatures for formation of skarns.

Even in hand specimens, the calcareous rocks of the tiny Pyle's limestone occurrence (Fig. 1; loc 4) can be seen to be recrystallized (Whitelaw, 1954); the metamorphism is presumed to have been connected with the nearby Brothers Syenite. The conodonts are transparent, indicating CAI values around 8, and much higher annealing temperatures than for the four other occurrences considered here. Three small limestone occurrences on the western flank of Morass Creek about 1.5–2 km above its junction with the Gibbo River are reported to have undergone skarn formation (Fig. 2; Birch et al. 1995; VandenBerg et al. 1998a: 205, 1998b); these were not sampled.

EASTERN VICTORIAN SILURIAN LIMESTONES: ALLOCHTHONOUS, AUTOCHTHONOUS, OR AN ENVIRONMENTAL MEDLEY?

VandenBerg et al. (1998a, 2000: p. 89) have argued for allochthoneity of the Silurian limestones of the Wombat Creek and Enano Groups of eastern Victoria. They have suggested, with some reservations due to generally poor exposures, that the numerous limestone occurrences in these groups reflect carbonate accumulation on "lost" carbonate platforms (without terrigenous clastics) followed by displacement as olistoliths into deep-water contexts. Viewed this way, such limestones are taken to lack constraining age-significance for sequences in which they are now found. Llandovery and Wenlock ages indicated by conodont data from the Enano Group (notably Simpson & Talent 1995) and for the Wombat Creek Group (herein) are therefore to be discounted.

We accept that inferences as to autochthoneity or otherwise of most Cambrian–Pragian limestone occurrences in eastern Victoria should be approached with caution, especially in the absence of other palaeontological data — such as from graptolites or acritarchs — in the enclosing clastic sediments. Many such occurrences, long considered autochthonous, such as the Cambrian limestone-charged channel deposits and limestone olistoliths of the Dolodrook River (Talent et al. unpub. data), and the Early Devonian limestones of the Walhalla Synclinorium from Coopers Creek to Loyola (Mawson & Talent 1994) — the limestones of the Tyers-Boola area and minor parallel-bedded occurrences in the Wilson Creek Shale being the obvious exceptions — are indeed allochthonous, having been lithified prior to being dislodged and transported downslope. And we believe that at least some of the limestone occurrences in the Wombat Creek and Enano Groups are also allochthonous, but hesitate to assume all are allochthonous, and even more so that age-inferences from their faunas should be ignored — especially when shells were not broken or not even disarticulated before burial and lithification.

A. WOMBAT CREEK GRABEN (WOMBAT CREEK GROUP)

1. Mitta Mitta River

The elegant exposures now displayed as a result of erosion by waters of the Dartmouth Dam around the "Lower Mitta" limestone (VandenBerg et al. 1998a, 1998b) on the right and left flanks of the dam were a principal focus for the present investigation. Most attention was devoted to the right (eastern) flank of the dam (Loc. 1 in Appendix). Up-section, a gradual change from bedded to massively bedded limestone is followed by gradual change back through bedded limestones to interbedded, often crinoidal, limestones and mudstones. The overall upward decrease in calcareous content of the upper limestone-mudstone sequence is interpreted as reflecting a deepening event. The upper limestone-mudstone sequence seems also to reflect lack of lithification of some of the carbonate materials prior to reaching their final resting place, but this needs closer study. Retention of coherency of such a sequence during downslope transport seems unlikely, but we hesitate to reject the possibility that this limestone-clastic occurrence is olistolithic. We interpret the sequence as having probably accumulated *in situ*.

Upstream on the left bank of the Mitta Mitta River are intervals of conglomerate within the prevailing siltstone–arenite sequence with two small patches with loose chunks of white limestone or marble sluiced out by the waters of the Dartmouth Dam; these limestones have failed to produce conodonts and appear to have been allochthonous. The superbly exposed limestone and calcareous mudstone body (Whitelaw 1954: fig. 2F; "Meanders 3" limestone lens of VandenBerg et al. 1998a) outcropping in a cliff on the right flank of the Mitta Mitta River about 3.6 km upstream from its junction with Wombat Creek was noted earlier. We view this occurrence, with prominent stylobrecciation, as probably autochthonous because of the wide range of lithologies, and the gradual transition from massive through bedded limestone to calcareous mudstones with limestone interbeds. In our view, it would have been difficult for such a sequence to retain stratigraphic coherence during major downslope displacement.

2. Gibbo River

We suspected that, because of association with conglomerates, the Gibbo River limestone occurrences mapped by Whitelaw (1954: figs. 3A and 3B) could be allochthonous. The Silver Flat limestone (Whitelaw 1954: fig. 3B), outcropping poorly on both flanks of the Gibbo River, mostly rather marmorised and/or metamorphosed, and mainly covered by alluvials, could well be a large olistolith, 300 m or more in length, but possibly extending to the

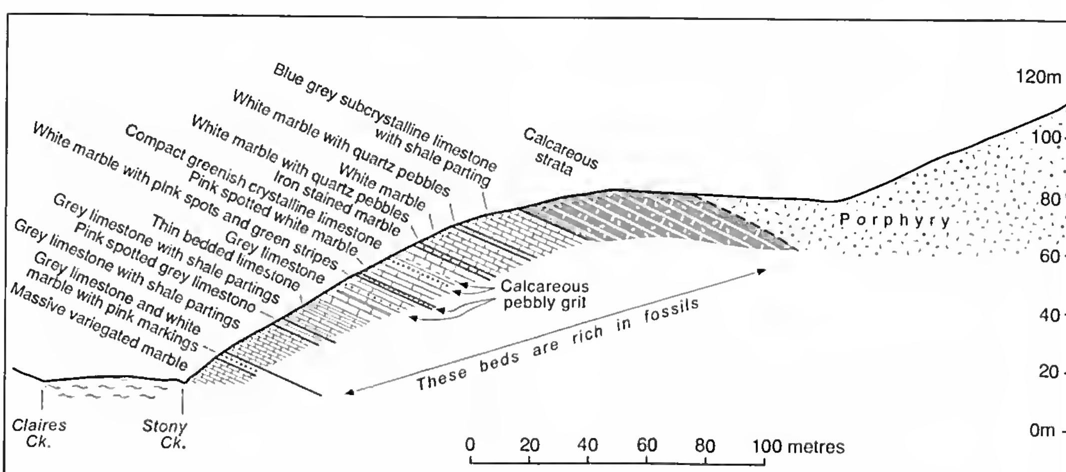


Fig. 4. H. S. Whitelaw's (1954: fig. 1) section, oriented northeast, crossing Claire and Stoney Creeks about 80 m downstream from Charles Summer's northern marble quarry; lithologies in this sequence, now viewed as portion of the Cowombat Siltstone, are according to Whitelaw; the porphyry is Snowy River Volcanics (Early Devonian). This sequence, but with not the same alignment, together with overlying and underlying strata was sampled (185 samples) for conodonts by Simpson & Talent (1995: text-figs 2, 6, 7) along their sections SC (in part), SCA and SCV.

south-southeast beneath Cainozoic basalt and colluvial cover for > 1,000 m in length. Sampling of this occurrence failed to produce conodonts.

We agree with VandenBerg et al. (1998a, 1998b) that their "Lower Gibbo [limestone] olistolith" (Whitelaw 1954: fig. 3^A) is almost certainly an allochthonous block. but wave-action by the Dartmouth Dam has not revealed contacts between this massive limestone/marble body and the nearby conglomerate and fossiliferous shales.

The Brammall Bluff occurrence (= Whitelaw 1954, Fig. 3^B; = "Hairpin limestone olistolith and skarn" of VandenBerg et al. 1998a, 1998b) is complex, consisting of massive, yellow-buff-weathering carbonate for the first c. 75 m of outcrop, stratigraphically above which (upstream), commencing at $5607_{96}59314_{63}$ on Benambra 1:50,000 topographic sheet 8424-3, the sequence becomes bedded with thin, irregular, rather bioclastic and nodular limestones (up to 2 cms thick) for about 37 m of outcrop. Eleven samples collected in this interval were acid-leached for conodonts. Farther upstream (for an additional c. 25 m) are yellow-buff-weathering carbonate blocks (to 5-m scale). These appear lithologically similar to the first 75 m of outcrop. They are not *in situ*, but appear to be olistoliths exhumed from the clastic sequence upslope, though none were noted within that sequence as presently exposed. We did not investigate the petrology of the yellow-buff-weathering carbonates, but were struck by the relatively good preservation of the fossils, mostly tabulate and rugose corals, occurring in isolation in matrix or in the thin beds of limestone within the clastic–cum–carbonate sequence. We accept that this tract has olistoliths (the yellow-buff-weathering carbonates), but suggest it also has beds of limestone apparently emplaced before lithification. Because of this we suggest that whatever palaeontologic information (mostly tabulate and rugose corals) can be derived from these limestones should not be dismissed in discussions of age of the associated strata.

Reconnaissance sampling of the "lower Gibbo" and Silver Flat occurrences failed to produce conodonts, but the sampled section through the Brammall Bluff occurrence (Loc. 2 — described above) produced sparse but useful faunas (Table 1). As indicated in the discussion of the conodont fauna above, it is possible to ascribe a relatively chronologically constrained time-interval to deposition of this sequence, and, as will be argued below, to infer broad synchroneity of Early Silurian carbonate deposition in the Wombat Creek Graben and the Limestone Creek Half-graben to the east.

3. Wombat Creek and Toak's Gap

Our sampling of the Toak's Gap outcrops has failed to produce conodonts on several occasions but one occurrence, at the southeast end of the Quart Pot limestone tract (Loc. 3), possibly a continuation of the Toak's Gap occurrence, has produced a faunule consisting of elements herein interpreted as *Ozarkodina* aff. *cadiaensis*.

4. Pyle's limestone deposit

Despite poor exposures, the parallel bedding of the thin limestones we collected and acid-leached leads us to believe this occurrence is autochthonous. VandenBerg et al. (1998a) suggest that the Pyle's occurrence may be a tiny erosional remnant of limestone deposits that were much more extensive during Silurian times. They referred the Pyle's occurrence to the Undowah Mudstone, the oldest unit of the Wombat Creek Group. If this stratigraphic allocation is accepted, and the late-Ludlow–Přídolí age we attribute to this occurrence is also accepted, all or virtually all of the post-Undowah units of the Wombat Creek Group would be Devonian in age! We suggest, however, that this isolated occurrence is Gibbo River Siltstone, or possibly a younger unit of the Wombat Creek Group not represented in the main outcrop area of Wombat Creek Group (Fig. 2).

Our experience in investigating conodont faunas from allochthonous carbonate bodies — e.g., the Walhalla Synclinorium of eastern Victoria (Mawson & Talent 1994), the Broken River region of north-eastern Queensland (Sloan et al. 1995; Talent et al. 2003b) and the eastern flank of the Hill End Trough and the Tamworth Belt of New South Wales (Mawson et al. 1998; Talent & Mawson 1999) — indicates a high proportion of allochthonous carbonates in debris-flows have ages very little different from the age of the enclosing matrix, with a tendency to decrease in age up-sequence — as was demonstrated for the eastern flank of the Hill End Trough (Talent & Mawson 1999). Age-data from a single clast or olistolith may be problematic due to possibilities of platform collapse and downslope transport of olistoliths and smaller debris detached from deep within platform sequences. Dissection of carbonate plat-

forms upslope may, moreover, lead to increasing proportions of older clasts up-sequence, as was encountered with the carbonate clasts of the Thatch Creek section of the Perry Creek Formation of northeastern Queensland (Sloan et al. 1995). We believe, nevertheless, that "clast ages", judiciously evaluated, may be valuable where unequivocally autochthonous limestone horizons appear to be lacking.

5. *Summary*

We have found no compelling evidence for all limestone occurrences in the Wombat Creek Group being allochthonous or, alternatively, all autochthonous. We suggest that some of the Wombat Creek Group limestone occurrences are most likely allochthonous, but others appear to be autochthonous. The Brammall Bluff occurrence (Loc. 2) we suggest is substantially allochthonous, but portions of the sequence — because of thin, parallel-bedded limestones, interpreted as having been lithified subsequent to deposition — are believed to be largely if not entirely autochthonous, and conodonts from them (Table 1) constrain the age of the strata with which they are interleaved. The majority of other limestone occurrences in the Wombat Creek Group — with outcrops not allowing resolution of relationships to nearby clastics — are best categorised as suspect.

B. LIMESTONE CREEK HALF-GRABEN (ENANO GROUP)

Prior to our sampling of various sequences in the northern part of the Limestone Creek Half-graben, all carbonates in the region had been accorded a generalised Late Silurian age (e.g., VandenBerg 1988; Walley et al. 1990). Our sampling of numerous carbonate intervals in this region revealed a much broader spectrum of ages: from early Llandovery to Přídolí *eosteinhornensis* Zone (Simpson & Talent 1995; Talent et al. 2003a). Subsequently, VandenBerg et al. (1998a, 2000) suggested that the limestone occurrences in the Enano Group, cropping out in the headwaters of the Indi, Buchan and Tambo Rivers, may be allochthonous and that palaeontologic data derived from them by us (Simpson & Talent 1995) may not be compelling for dating associated strata. As this suggestion has implications for the tectonic scenario presented by VandenBerg and his colleagues, we dwell a little on the question of allochthoneity *versus* autochthoneity of the carbonate units for which we have previously presented conodont data.

Our sparse conodont data from the McCarty's limestone lens (Simpson & Talent 1995: text-fig 3A) are biostratigraphically consistent with it being a stratigraphically coherent body. It has produced the oldest conodont assemblages (early Llandovery, Rhuddanian) so far obtained from the region. Whether or not it is a fault-bounded body, autochthonous, or a large olistolith cannot be determined because of the absence of exposures displaying relationships of the limestone to nearby clastics.

Because of its well-bedded character, we are disinclined to accept an allochthonous interpretation for the highly fossiliferous Lobelia limestone lens (Simpson & Talent 1995: text-fig. 4) of the Reedy Creek area; it has produced conodonts indicative of the late Llandovery–earliest Wenlock *celloni–amorphognathoides* interval. The Farquhar limestone lens, about 1.5 km along strike from the Lobelia lens, is conspicuously more massive and more recrystallized than the latter. It could be allochthonous but, because it is the same age as the Lobelia lens and located more or less on strike with the latter, we are not inclined towards an allochthonous interpretation for this limestone lens, but such is indeed possible. Unequivocal answers might be possible from a minimum of trenching across strike of the boundaries of these two occurrences.

The Claire Creek–Stoney Creek outcrop-tract, in the central parts of the region, consists of two main limestone units separated by a pelitic sequence with subordinate carbonates, followed by a sequence with generally decreasing ratio of carbonate to clastics. In an earlier phase of nomenclatorial zeal (Talent et al. 1975), the entire package was referred to — in line with recommendations of the then code of stratigraphic nomenclature, to emphasize prominent or dominant lithologies — as the Claire Creek Limestone Member. Though this section was heavily sampled (367 samples) over a distance of 1.4 km (Simpson & Talent 1995, text-figs. 2, 6, 7, tables 2–5), it displays no inconsistencies in conodont biostratigraphy. VandenBerg (unpub. ms.) however challenged this, pointing out an overlap of two index taxa (*A. ploeckensis* and *O. sagitta*), previously thought to be chronologically separate, in the lower part of the upper Claire Creek limestone unit. This we regard as trivial, with no bearing on the regional

synthesis previously presented (Simpson & Talent 1995).

Despite metamorphism to lower greenschist facies and poor yields of conodonts, particularly for the lower limestone unit, data are sufficient to indicate deposition through a large slice of Silurian time (cf. Table 2; Simpson & Talent 1995). Near basal samples of the lower limestone unit have produced a tentatively identified taxon *Ozarkodina aldridgei* that suggests an earliest possible age of middle Aeronian (Simpson & Talent 1995). The higher intervals of the lower limestone unit have produced poor faunas typical of the late Llandovery to early Wenlock *celloni* and *amorphognathoides* zones. Equivocal fragmentary specimens from near the top of the lower unit suggest that, like the McCarty's limestone lens, the lower limestone unit may extend into the "post-*amorphognathoides*" interval of the Wenlock. The lower intervals of the "upper limestone unit" (cf. fig. 5) are typified by taxa indicative of a broad Wenlock age. Higher in the unit, there is an overlap of the zonal index species of the typically European Wenlock *sagitta* Zone with the first appearance of zonal index species of the cosmopolitan Ludlow *ploeckensis* Zone. We regard this apparent biostratigraphic disparity as being inconsequential.

The identification of the single specimen of *O. saggita* has been questioned by Corradini & Serpagli (1999). One of us (AS) has subsequently had the opportunity to compare the specimen with topotype material of *O. saggita* from Europe and must agree that the original identification is equivocal. More sampling is required to resolve the issue. Should the interpretation of Corradini & Serpagli (1999) prove correct, this implies resumption of carbonate sedimentation in the Limestone Creek region in the early Ludlow rather than the late Wenlock. It would also remove any scintilla of biostratigraphic dissonance that could possibly be construed as supporting evidence for an allochthonous origin.

Faunas above this level, high in the "upper limestone unit", are typically Ludlow in aspect (Simpson & Talent 1995). Constrained by data from the overlying and underlying limestone units, the intervening pelitic sequence is therefore inferred to be broadly Wenlock in age. Intermittent carbonates in the predominantly clastic sequence overlying the "upper limestone" interval also yield broadly Ludlow faunas. Despite the lack of index species, this latter sequence is thought to extend well into the later Ludlow.

In our earlier sampling (Simpson & Talent 1995) we gave special attention to the Claire Creek–Stoney Creek sequence because of the exceptional length of the sequence, and the lengthy intervals of excellent exposure. The diverse lithologies are indicated in a cross-section by Whitelaw (1954, section A, redrawn as Fig. 4 herein). From our experience, such lithologically diverse and generally thin-bedded sequences characterized by a broad spectrum of lithologies and contrasting competence — with a significant proportion of mudrocks — would have been prone to disintegration during major downslope movement. Moreover, brachiopods from the various lithologies in this section, admittedly not abundant, are overwhelmingly articulated. Though conceivable, this is not what would be anticipated if the unlithified sediments had undergone substantial downslope transport as olistostromes. We are therefore inclined to view this, the most important Cowombat Siltstone sequence, as autochthonous. We accordingly accept the conodont data obtained from it as indicating true ages for the sequence as a whole — i.e. from mid-Aeronian (mid-Llandovery) to the late Gorstian (Early Ludlow) *ploeckensis* Zone, probably extending into the Ludfordian (late Ludlow) — and not depositional ages: somewhere on an adjacent platform prior to being dislodged and deposited in basinal contexts.

The largest tract of Silurian limestone in the valley of Limestone Creek, extending for approximately 2 km from Jim Spean Creek (Kimberley Hut area) through the Pendergast's Cave and Sheehan's Bluff areas (Whitelaw 1954, fig. 1C), may be interpreted as a single autochthonous or allochthonous slab or, because of a substantial tract of alluvials and older terrace gravels about Painter Creek, interpreted as possibly two large olistoliths. We incline to the former interpretation but, because of poor exposures of the nearby clastics and absence of exposures displaying contacts between the limestones and clastics, the nature of this body (or bodies) cannot be compellingly demonstrated. The age of this body (or bodies) is uncertain. No conodonts were obtained from a section sampled across strike through Sheehan's Bluff, but a few poorly preserved and chronologically inconsequential *Panderodus* obtained from samples from a section approximately 600 m along strike north of Sheehan's Bluff give hope that additional sampling may eventually provide chronologically useful data.

Among limestone occurrences only cursorily examined and sampled by us are some which have parallel-bedded and occasionally bioclastic limestones, e.g. the Philip's Bluff and Little Stoney

Creek occurrences (Whitelaw 1954: fig. 1[B]); these we believe are probably autochthonous. Like the Sheehan's Bluff section (see above), these have produced only a few poorly preserved *Panderodus*. Others, such as those on the western flank of Limestone Creek in the northern part of Whitelaw's fig 1[C] are parallel-bedded and interbedded with clastics; these limestones appear to be autochthonous but could be allodapic. We suspect that the body through which we sampled our section LC (Simpson & Talent 1995: upper part of text-fig. 2; table 1) with, inter alia *Ozarkodina australensis*, may be allochthonous, but there is an absence of exposures displaying relationships of the limestone to nearby clastics.

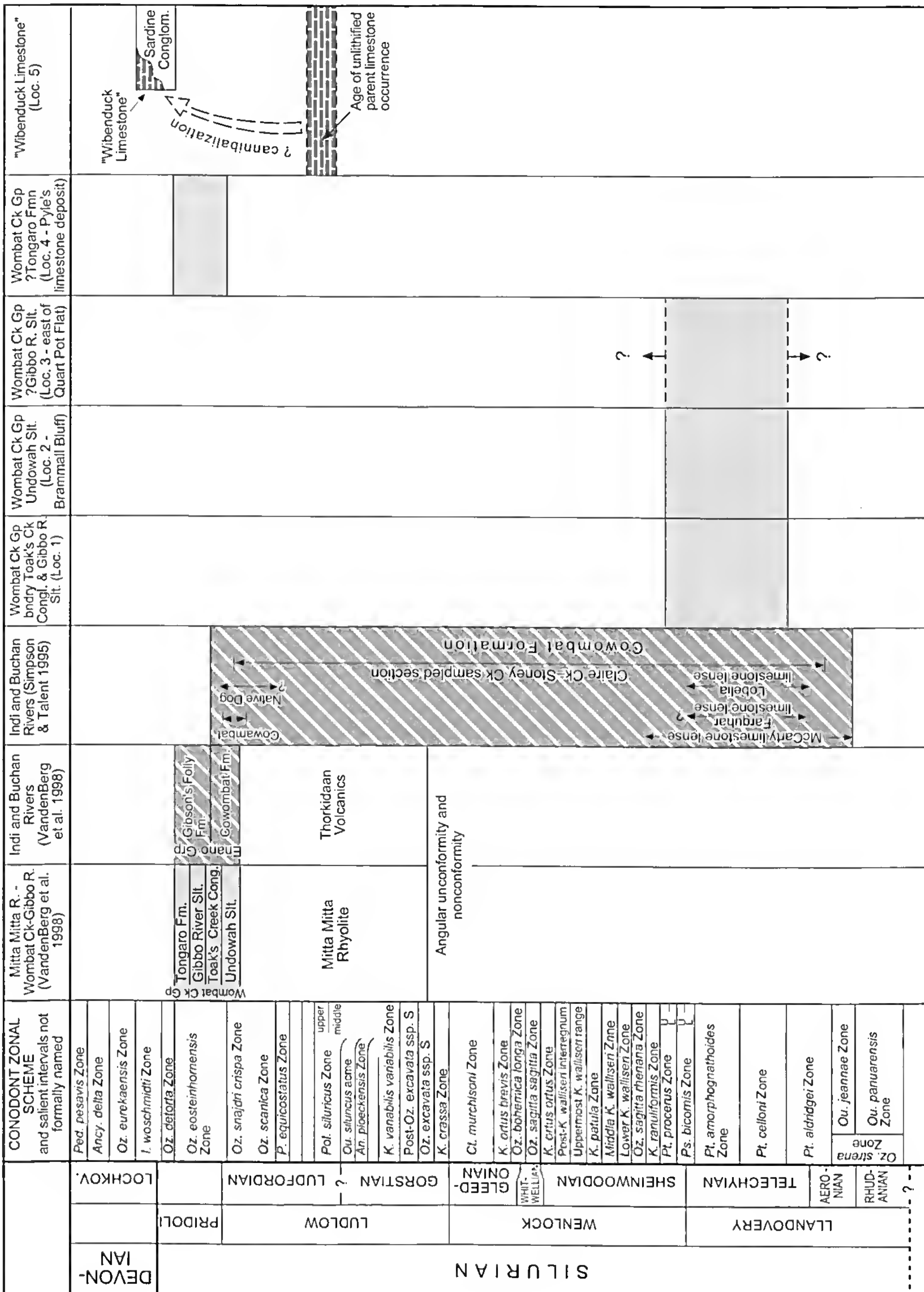
The occurrences in the valley of Annabella Creek and adjacent parts of Limestone Creek (Whitelaw 1954, fig. 1[A]) appear to be allochthonous. These and limestones intimately associated with acid and intermediate volcanics, volcanic breccias and greywackes farther south in the vicinity of the Wilga and Currawong prospects (Allen 1991) appear also to be allochthonous, but these occurrences need to be cautiously probed for relationships in the field and from the large corpus of bore cores available at the Benambra Mine. At least one limestone occurrence in this area, outcropping on and adjacent to the Teapot Track Creek in the vicinity of 837_0080_9, consists of limestone clasts and is therefore unequivocally allochthonous. This occurrence failed to produce conodonts.

An isolated limestone lens among richly fossiliferous calcareous mudstones at Cowombat Plain has yielded late Ludlow *crispa* Zone conodonts (Simpson et al. 1993). The interval of fine clastics above this lens, exposed in Native Trout Creek, is therefore most probably Přídolí in age. Conodonts from limestones associated with clastics at Native Dog Plain are generalised Late Silurian associations, but high in the sequence are faunas typical of the Přídolí *eosteinhornensis* Zone. The range-base of the name-giving taxon predates the Ludlow–Přídolí boundary in many parts of the world (Aldridge & Schönlaub 1989). However that may be, the occurrence at Native Dog Plain seems to be the youngest preserved horizon in the tracts of Silurian rocks outcropping in the headwaters of the Indi, Buchan and Tambo Rivers. These sequences extend the age-spectrum for the Cowombat Formation to higher horizons than those encountered in the Stoney Creek–Claire Creek sequence. The massive limestone in the lower part of the Native Dog sequence aside, these sequences are shaley with minor limestones, not the sort of sequences we would anticipate likely to retain coherence during grand-scale downslope movement.

In summary, though we earlier noted that the Enano Group included allochthonous limestones (Conaghan et al. 1976: 529, as Cowombat Group), we did not view all limestone occurrences in that unit, nor, for instance at Tyers River and Tamworth areas cited in the same paragraph, to be exclusively allochthonous, though, regrettably, this was not unequivocally asserted. Our subsequent sampling of the Enano Group and Wombat Creek Group have produced no compelling evidence for all limestone occurrences in the two regions to be exclusively either allochthonous or autochthonous. We accept that some of the limestone occurrences in both regions are allochthonous, but others (possibly a minority) appear to be autochthonous and therefore of value in dating the enclosing sediments. Others, where outcrops do not allow resolution of relationships to nearby clastics, are best categorised as suspect until additional data become available.

We draw attention to the profound influence of faulting in preservation of the Silurian sequences in the Wombat Creek Graben and Limestone Creek Half-graben, and see no reason why these fault boundaries have any necessary relationship to the former boundaries of the sedimentary "basin" (or "basins") in which these sedimentary packages accumulated. Similarities, admittedly very broad, in depositional sequence and in chronologic alignments between the two regions suggest that the sequences in the two regions may be viewed as possibly now-disjunct portions of a formerly continuous sedimentary pile. In other words, their preservation in now separate tracts may be an artifact of post-depositional tectonics.

Table 2. Silurian correlations advocated on the basis of conodont data presented here and by Simpson et al. (1993) and Simpson & Talent (1995, 1996), compared with correlations suggested by VandenBerg et al. (1984–1999, principally 1998a). Scale on the left is based on Zhang & Barnes (2002) for the Llandovery, Jeppsson (1997c) and Calner & Jeppsson (2003) for the Wenlock, and Jeppsson (in Eriksson 2001) for the Ludlow and Přídolí. Abbreviations for generic names in the conodont zones are as follows: *An.* = *Aucoradella*, *Ancy.* = *Ancyrodelloides*, *Ct.* = *Ctenognathodus*, *I.* = *Icriodus*, *K.* = *Kockelella*, *Oz.* = *Ozarkodina*, *Ou.* = *Oulodus*, *Ped.* = *Pedavis*, *Pol.* = *Polygnathoides*, *Ps.* = *Pseudooneotodus*, *Pt* = *Pterospathodus*.


CONODONT ZONAL SCHEME and salient intervals not formally named
Mitta Mitta R. - Wombat Ck-Gibbo R. (VandenBerg et al. 1998)
Indi and Buchan Rivers (VandenBerg et al. 1998)
Indi and Buchan Rivers (Simpson & Talent 1995)
Wombat Ck Gp bndry Toak's Ck Congl. & Gibbo R. Slt. (Loc. 1)
Wombat Ck Gp Undowah Slt. (Loc. 2 - Brammall Bluff)
Wombat Ck Gp ?Gibbo R. Slt. (Loc. 3 - east of Quart Pot Flat)
Wombat Ck Gp ?Tongaro Fmn (Loc. 4 - Pyle's limestone deposit)
"Wibenduck Limestone" (Loc. 5)
DEVONIAN
SILURIAN
LOCHKOV.
PRIDOLI
LUDLOW
WENLOCK
LLANDOVERY
LUDFORDIAN
GORSTIAN
GLEEDONIAN
WHITWELLIAN
SHEINWOODIAN
TELECHYIAN
AERONIAN
RHUDDANIAN
Ped. pesavis Zone
Ancy. delta Zone
Oz. eurekaensis Zone
I. woschmidti Zone
Oz. detorta Zone
Oz. eosteinhornensis Zone
Oz. snajdri crispa Zone
Oz. scanica Zone
P. equicostatus Zone
Pol. siluricus Zone
upper
middle
Ou. siluricus acme
An. ploeckensis Zone
K. variabilis variabilis Zone
Post-Oz. excavata ssp. S
Oz. excavata ssp. S
K. crassa Zone
Ct. murchisoni Zone
K. ortus brevis Zone
Oz. bohemica longa Zone
Oz. sagitta sagitta Zone
K. ortus ortus Zone
Post-K. walliseri interregnum
Uppermost K. walliseri range
K. patula Zone
Middle K. walliseri Zone
Lower K. walliseri Zone
Oz. sagitta rhenana Zone
K. ranuliformis Zone
Pt. procerus Zone
Ps. bicornis Zone
Pt. amorphognathoides Zone
Pt. celloni Zone
Pt. aldridgei Zone
Ou. jeannae Zone
Ou. panuarensis Zone
Oz. strena Zone
Wombat Ck Gp
Tongaro Fm.
Gibbo River Slt.
Toak's Creek Cong.
Undowah Slt.
Mitta Mitta Rhyolite
Angular unconformity and nonconformity
Enano Grp
Gibson's Folly Fm.
Cowombat Fm.
Thorkidaan Volcanics
Cowombat Formation
Cowombat
Native Dog
Claire Ck-Stoney Ck sampled section
Lobelia limestone lense
Farquhar limestone lense
McCarty limestone lense
"Wibenduck Limestone"
Sardine Conglom.
? cannibalization
Age of unlithified parent limestone occurrence

C. SARDINE CREEK ("WIBENDUCK LIMESTONE")

A tract of Silurian rocks about 32 km north-northeast of Orbost first noted by Stirling (1888a) and formerly referred to as the Sardine Beds (Talent et al. 1975; Taylor 1984), was regarded as consisting of two units, the Sardine Conglomerate (a submarine fan deposit) overlain by Wibenduck Limestone (VandenBerg 1988; VandenBerg et al. 1992). There are no exposures of the contacts between the Wibenduck Limestone and adjacent tracts of conglomeratic Sardine Conglomerate *sensu stricto* nor of the former with the Warbisco Shale (Ordovician), though it is probable that the latter is a fault boundary. We interpret the "Wibenduck Limestone" to consist of clasts of various carbonate and calcareous lithologies, lithified before cannibalisation and incorporation into the fan deposit. We thus regard it as a limestone-charged debris flow at the top of the spectacular Sardine Conglomerate fan deposit (Talent et al. 2003a) rather than as a discrete formation.

Conodonts from the "Wibenduck Limestone", reported (VandenBerg 1988: 131) but not documented previously, were reviewed by Talent et al. (2003a). They concluded that the fauna is consistent with a generalized Ludlow age and opined that the fan may be interpreted as a reflection of Late Silurian synorogenic sedimentation. Conodonts recovered in this study generally indicate a mid to late Ludlow age (probably latest Gorstian–earliest Ludfordian) consistent with the cannibalisation and redeposition scenario suggested here.

The conodonts obtained from acid-leaching limestone float and from samples from a tiny quarry beside the Scanlon Creek Track (type locality of the "Wibenduck Limestone", VandenBerg et al. 1992: 27; see Appendix, loc. 5) have a high breakage ratio, consistent with appreciable transport of much of the fauna prior to lithification, somewhere upslope — from wherever the clasts may have been derived. The age indicated by the "Wibenduck Limestone" could thus be older, even appreciably older, than the age of accumulation of the Sardine Conglomerate fan deposit. We suggest the latter to be an analogue of the Sharpeningstone Conglomerate of the Yass district of southern New South Wales, a unit closely connected chronologically with the onset of the Bowning Orogeny — cf. conodont data for the Elmside Formation and Sharpeningstone Conglomerate in Link & Druce (1972).

TECTONIC IMPLICATIONS

A "package" of events — deformation, regional metamorphism, and plutonism — during latest Ordovician–Early or mid-Silurian times (the traditional view), or Late Silurian in eastern Victoria (VandenBerg et al., e.g. 1998a, 2000) — has long been assumed to have impacted more dramatically on the geological evolution of eastern Australia than any other "package" of events during the last 500 million years. This has long been referred to as the Benambran Orogeny (e.g. Browne 1947; Packham 1969; Scheibner 1998; Reed 2001). During the last decade, an alternative view has developed, that Silurian and Devonian orogenic events, including the "Benambran" events, were not clustered into discrete time-slices — see debate: Gray & Foster 1997, 1998, 1999; Gray et al. 1997; Foster et al. 1999, 2000; Foster & Gray 2000; VandenBerg 1999; VandenBerg et al. 2000; Collins & Hobbs 2001). That there can be such divergent opinions underlines the poor knowledge of most major events (or sub-events) during that interval, especially as regards time-control on the sedimentary sequences reflecting events "set in train" by deformation.

In a recent survey of stratigraphic alignments for the Silurian of Australia, Talent et al. (2003a) re-affirmed that there was indeed a hiatus equating with much or all of early and middle Llandovery time in eastern Australia and, in most cases, a striking angular unconformity associated with a profound contrast in tectonic style between juxtaposed units. In most areas, such as in the vicinity of Canberra, Quidong, Bungonia and the Broken River region of northeast Queensland, the dramatic contrast in deformation between the juxtaposed units implies greater tectonic activity than occurred during the remainder of Silurian and Devonian time. However, during a recent debate on diastrophism in the Lachlan Fold Belt of south-eastern Australia (see references above), contrasting scenarios were presented for the entire Late Ordovician–Devonian interval (including the "Benambran" time-slice): west–east continuous (non-episodic) diastrophism connected with essentially continuous subduction-induced deformation ("Lachlan Orogeny") *versus* discrete/episodic events. Disagreement included the significance regarding spatial and temporal variation in deformation that might be inferred from Ar–Ar dates on white micas — argued to reflect migration of the cleavage front in the "deforming sedimentary pile". The Ar–Ar database is, however, sparse and has been obtained mostly from the western part of the Lachlan Fold Belt. The eastern part of the Lachlan

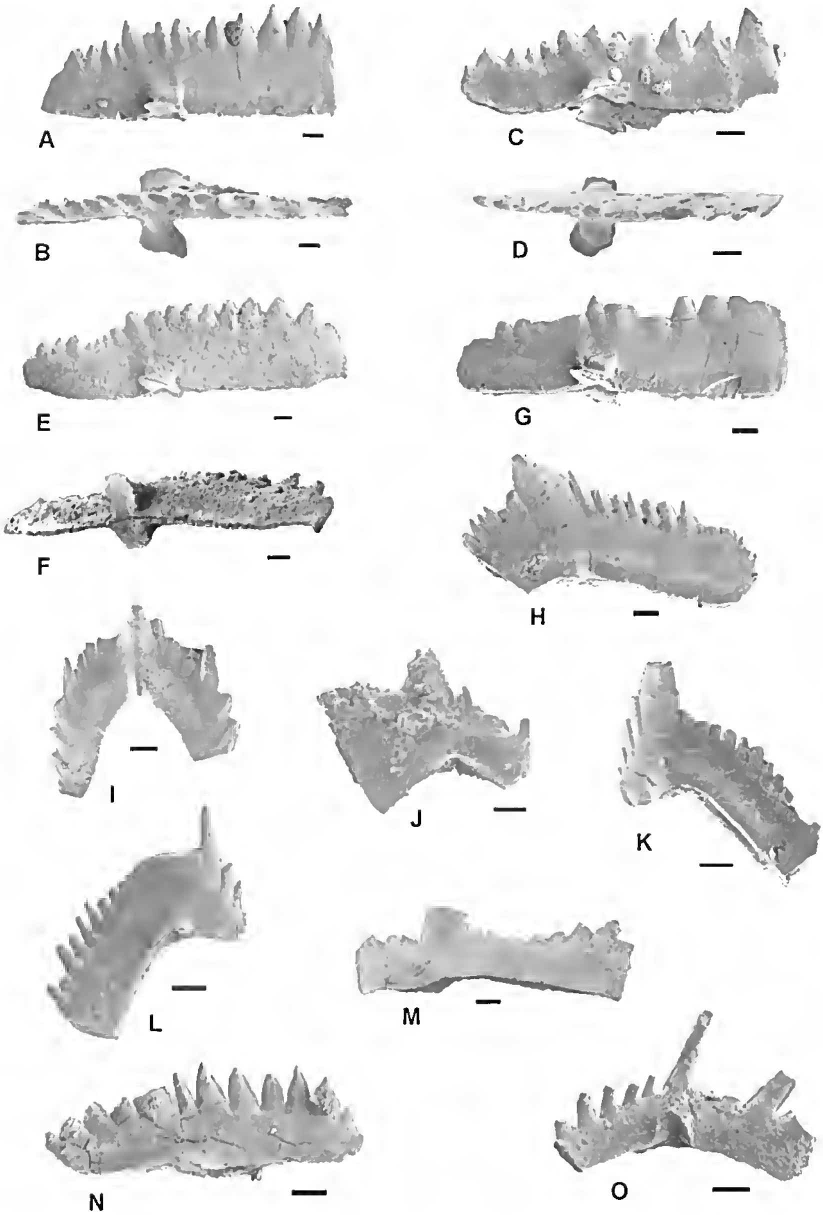


Fig. 5. Early Silurian (Llandovery) conodonts from stratigraphic section through the "Lower Mitta" limestone body on the right (east) flank of the Mitta Mitta River, eastern Victoria. The location is indicated on Fig. 2 and determinations are presented in Table 1. All specimens are housed in the Australian Museum, Sydney, with prefix AMF.
A-I, *Ozarkodina cadiaensis* Bischoff, 1986. A, B. Pa element, 3.2m, inner lateral and upper views respectively of AMF 125116. C, D. Pa element, inner lateral and upper views respectively of AMF 125117, 27,4m. E, F. Pa element, inner lateral and lower views respectively of AMF 125118, 15.7m. G. Pa element, outer lateral view of AMF 125119, 22.5m. H. Pb element (incomplete), lateral view of AMF 125120, 22.5m. I. Sa element, inner lateral view of AMF 125121, 27.4m. J. Sb element, inner lateral view of AMF 125122, 15.6m. K. M element, inner lateral view of AMF 125123, 15.6m. L. M element, inner lateral view of AMF 125124, 15.6m. M-O. *Ozarkodina australensis* Bischoff, 1986. M. Sc element of AMF 125125, 20.5m. N. Pa element, inner lateral view of AMF 125126, 20.5m. O. Sb element of AMF 125127, 23.5m.

Fold Belt, including the areas that form the foci of the present report, has large tracts that appear to be less amenable to regional Ar–Ar dating of metamorphic micas, so palaeontologic data in conjunction with sedimentary and tectonic data retain importance in the discussion for eastern Victoria and south-eastern New South Wales.

We suggest that whatever tectonic scenario is put forward should not ignore the evidence of well-dated major unconformities reflecting intense deformation, or biostratigraphic data (unless derived from demonstrably allochthonous material). If as we suggest, some of the Enano and Wombat Group carbonate intervals are autochthonous and pre-Ludlow, then the tectonic scenario should be made to accommodate these data. Our view is the traditional view: that a substantial "package" of events — deformation, regional metamorphism, and plutonism — indeed took place during the Llandovery, especially early- and mid-Llandovery times, but an integrated story of what happened (tectonic, igneous and sedimentary) during the Silurian has still to be spelled out with good chronologic underpinning. The picture is more complex than may at first appear. Some of the sequences, long asserted to be Late Silurian (e.g. by Walley et al. 1990), in fact fall within the latest Ordovician–Llandovery/earliest Wenlock interval. We are aware that linkages between deformation, uplift, erosion and derived sedimentation may be complex, with the possibility that unconformity-bound sedimentary packages resulting from erosion and sedimentation "set in motion" by a specific cycle of deformation could post-date the onset of the deformation by as much as "several million years" (Foster et al. 2000: 816) — and be diachronous. Clearly, there is a long way to go before the Benambran events have been adequately deciphered and compelling linkages established.

TAXONOMIC NOTES

Ozarkodina australensis Bischoff, 1986
Fig. 5, M–O, Fig. 6, H, K, L, O, P, Fig. 7, O.

Ozarkodina australensis Bischoff 1986: 126, pl. 22, figs 1–21. – Simpson & Talent 1995: pl. 7, figs 2–22.
Ozarkodina excavata eosilurica Bischoff 1986: 137, pl. 25, figs 10–34.
Ozarkodina sp. C Armstrong 1990: 96, pl. 14, figs 17–18, 20.

Remarks. Bischoff (1986) obtained several *Ozarkodina* specimens from mid-western New South Wales from earliest and pre-Wenlock strata, separated these into different taxa, and suggested an evolutionary relationship with the younger *Ozarkodina excavata excavata*. Simpson & Talent (1995: 140) placed two of these, *O. australensis* and *O. excavata eosilurica*, in synonymy. Closely similar Pa elements with short blades and straight to slightly concave basal margins were recovered from the Mitta Mitta Formation. Whilst these elements have a morphology superficially resembling the highly variable *O. excavata excavata*, numbers are too low to shed any further light on evolutionary relationships, so the taxonomy of Simpson & Talent (1995) is retained.

Ozarkodina cadiaensis Bischoff, 1986
Fig. 5, A–I, Fig. 7, H, L, M.

Ozarkodina cadiaensis Bischoff 1986: 132, pl. 24, figs 11–27, 30. – Simpson & Talent 1995: 142, pl. 7, figs 23–25.

Remarks. This taxon has a distinctive Pa element characterised by the V-shaped separation between the cusp and adjacent denticle, decline in denticle height from anterior to posterior, and the small rounded basal cavity with pinched basal margins. All elements of *Ozarkodina cadiaensis* are characterised by small closely packed denticulation and restricted basal cavities.

Bischoff (1986: 133–134) provided descriptions of the Pa, Pb, and M elements. In the symmetry transition series he recovered only the Sc element. In this study we recovered all of the above elements and identified distinctive Sa and Sb elements. Brief descriptions are given below.

Sa element: Alate element with minute basal cavity, high lateral processes with concave lower margins separated by an acute angle. Proximal denticles are erect, distal denticles inclined outwards giving an overall "fan-like" appearance.

Sb element: Digyrate element with small rounded basal cavity, one high lateral process and one low lateral process both with small closely packed denticulation abutting prominent cusp.

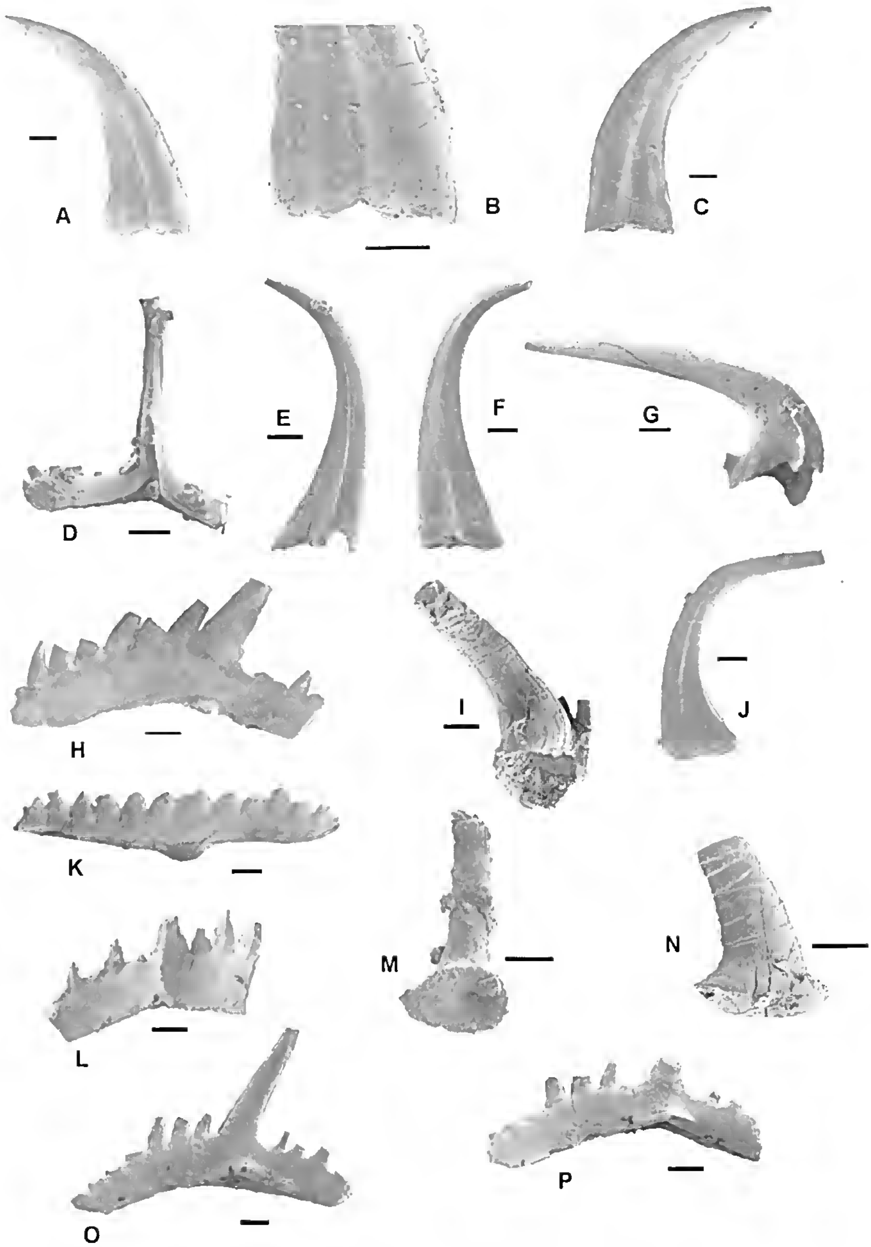


Fig. 6. Early Silurian (Llandovery) conodonts from stratigraphic section through the "Lower Mitta" limestone body on the right (east) flank of the Mitta Mitta River, eastern Victoria.
A-C *Panderodus* sp. A, B lateral view and enlargement respectively of AMF 125128, 22.5m. C. lateral view of AMF 125129, 22.5m. D. *Ozarkodina excavata excavata* (Branson & Mehl 1933) Sa element, inner lateral view of AMF 125130, 19.3m. E, F. *Panderodus unicostatus* (Branson & Mehl 1933) lateral views of AMF 125131, 3.2m and of AMF 125132, 19.3 m respectively. G, I, M, N. *Distomodus staurognathoides* (Walliser 1964). G. Sb element, lateral view of AMF 125133, 22.5m. I. Sc element (fragmentary), posterior view of AMF 125134, 19.3m. M-N Undifferentiated cones, 3.2.m, AMF 125135 and AMF 125136, respectively. H, K, L, O, P. *Ozarkodina australensis* Bischoff, 1986. H. Pb element, inner lateral view of AMF 125137, 18.3m. K. Pa element, upper view of AMF 125138, 3.2m. L. Sb element, inner lateral view of AMF 125139. O, P. Pb elements, inner lateral views of AMF 125140 and of AMF 125141, respectively, 3.2m. J. *Panderodus recurvatus* (Rhodes 1953) lateral view of AMF 125142, 15.6m.

Ozarkodina aff. cadiaensis Bischoff, 1986
Fig. 7, A–E.

Description. Pa element: Carminate element with a short posterior process and long anterior process. Lower margins of processes are straight, meeting at less than 180 degrees, giving a concave appearance to the lower margin. Small rounded basal cavity located in posterior half of element beneath, and slightly anterior to prominent cusp. Posterior process is low with two or three small proximal denticles and one larger distal denticle. Anterior process relatively high with seven or eight large denticles of generally equivalent size.

?Pb element: Angulate element with prominent cusp and large denticles (element incomplete).

?Sa element: Alate element with prominent cusp and thick processes with narrow ledges beneath subdued denticulation (element incomplete).

Remarks. Three different element types (two of which are represented only by fragmentary specimens) were recovered from the same sample from the southeastern end of the Quart Pot limestone. Morphological similarities enable them to be grouped tentatively in the one taxon.

The Pa element strongly resembles *Ozarkodina cadiaensis*, in particular with respect to the size and structure of the basal cavity. The main differences are the subdued denticulation on the posterior process, the more prominent cusp and the less obvious development of a V-shaped separation between denticles above the basal cavity. More specimens are required to establish whether this form is aberrant but within the range of intraspecific variation for *O. cadiaensis*, or whether it represents a separate taxon. Without intermediate morphologies it is not possible to imply this form is related in some way to *O. cadiaensis*; it is therefore left in open nomenclature.

Ozarkodina excavata excavata
(Branson & Mehl, 1933)
Fig. 6, D, Fig. 8, C, D, F.

For synonymy see Simpson & Talent (1995) and add the following:

Aspelundia fluegeli (Walliser): Percival 1998: Fig. 3.6.
Ozarkodina excavata (Branson & Mehl): Miller 1995: pl. 1, fig. 8.
Ozarkodina excavata excavata (Branson & Mehl) – Barca et al 1992: pl. 10, figs 3–5: – Sloan et al. 1995: pl. 12, figs 15, 18: – Simpson & Talent 1995: 147–153. pl. 8, figs 16–25, pl. 9, figs 1–24: – Colquhoun 1995: pl. 1, fig. 16: – Furey-Greig 1995: pl. 1, figs 12–14: – Carey & Bolger 1995: 79–81, Fig. 3G–H: – Serpagli et al. 1998: pl. 1.2.1, figs 4–5; pl. 1.2.2, fig. 1: – Corradini et al. 1998: pl. 1.3.1, fig. 1: – Ferretti et al. 1998: pl. 2.2.1, fig. 1: – Percival 1998: Fig. 4.2: – Talent & Mawson 1999: pl. 5, figs 1, 3–4; pl. 5, figs 1–4; pl. 6, figs 19–22; pl. 9, figs 8–9: – Cockle 1999: 120, pl. 3, figs 1–14: – Talent et al. 2003a: pl. 2, figs R–S, pl. 3, fig. S, pl. 4, fig. K.

Remarks. This is one of the most numerically abundant, highly variable and widely recognised conodont taxa recovered from Silurian strata. Simpson & Talent (1995: 147–153) discuss this subspecies and its differentiation from the older and probably closely related *Ozarkodina australensis*. The fauna from this study add no new insights to the question of the relationship between *O. excavata excavata* and *O. australensis*. It would be unwise to preclude the possibility that better faunas from more continuous sequences may indicate a closer phylogenetic relationship than inferred herein. Until this time the taxonomy and interpretations of Simpson & Talent (1995) are retained.

Ozarkodina martinssoni auriformis
Simpson, 2003
Fig. 8, A–B.

For synonymy see Simpson (2003) and add the following:

Ozarkodina martinssoni auriformis Simpson 2003 – Talent et al. 2003a: pl. 2, fig T.

Remarks. The distinctive Pa element of this taxon is readily separated from other Pa elements in this study such as *Ozarkodina cadiaensis* on the following morphological criteria. *O. martinssoni auriformis* has a distinctive two-level height of denticle development, and denticle-size is relatively even on both the anterior and posterior processes. *O. cadiaensis* has an undulose development of denticles in lateral outline. The basal cavities of *O. martinssoni auriformis* and *O. cadiaensis* are similar in having pinched margins close to the blade. The basal cavity

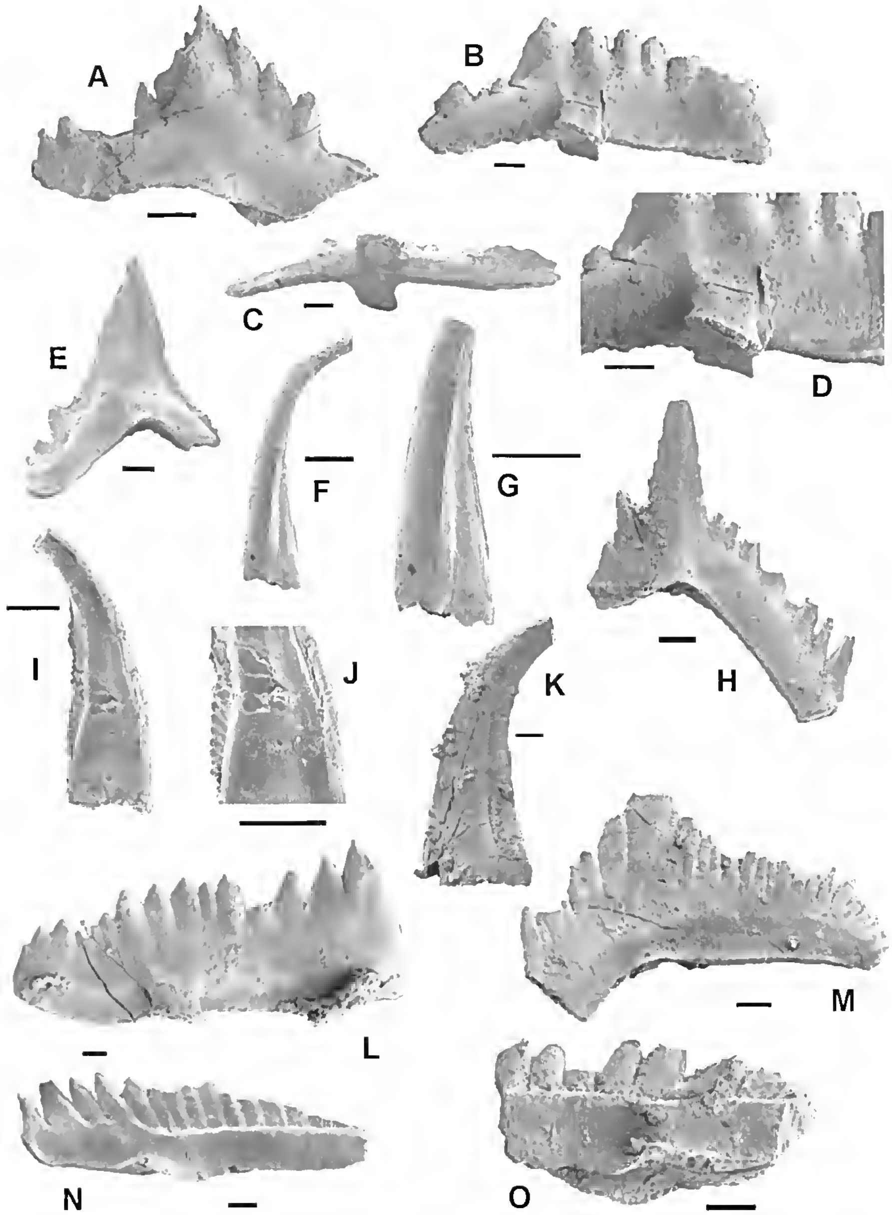


Fig. 7. Early Silurian (Llandovery) conodonts from stratigraphic section at Brammall Bluff on the Gibbo River (locality 2; = 'Hairpin limestone' of VandenBerg et al. 1998a), and from a spot sample at locality 3, at SE end of Quart Pot limestone tract. Locations are indicated on Fig. 2.

A-E. *Ozarkodina* cf. *cadiaensis* Bischoff 1986. A. Pb element, lateral view of AMF 125143, Loc. 3. B-D. Pa element, lateral view, lower view and enlargement of basal cavity respectively of AMF 125144, Loc. 3. E. Sa element, lateral view of AMF 125145, loc. 3. F, G. *Panderodus unicostatus* (Branson & Mehl 1933) lateral view and enlargement of AMF 125146, Loc. 2, 0.1m. H. *Ozarkodina cadiaensis* Bischoff 1986 M element, inner lateral view of AMF 125147, Loc. 2, 0.1m. I, J. *Pseudobelodella silurica* Armstrong 1990 aq element lateral view and enlargement respectively of AMF 125148, Loc. 2, 5.7m. K. *Panderodus* sp., lateral view of AMF 125149, Loc. 2, 5.7m. L, M. *Ozarkodina cadiaensis* Bischoff 1986. L. Pa element, inner lateral view of AMF 125150, Loc. 2, 0.1m. M. Pb element, lateral view of AMF 125151, Loc. 2, 0.1m. N, O *Ozarkodina australensis* Bischoff, 1986. Pa elements, lateral views of AMF 125152 and AMF 125153, respectively, Loc. 2, 0.1m.

of the former, however, is relatively larger than the latter.

Simpson (2003) provided the description and reconstruction of this taxon. It is geographically widespread and restricted to the interval from the Ludlow *siluricus* Zone through to the earliest Devonian *woschmidti* Zone.

Ozarkodina remscheidensis eosteinhornensis (Walliser, 1964)
Fig. 8, G.

For synonymy see Simpson & Talent (1995), supplemented by Mawson et al. (2003).

Remarks. This taxon has been discussed by Simpson & Talent (1995), *inter alia*, and additional interpretations concerning the phylogeny of the broader group were given by Mawson et al. (2003). A single Pa element was recovered from the Pyle's limestone unit. Despite one larger denticle on the anterior process, this poorly preserved element is characterised by a row of denticles of approximately uniform height, each being relatively perpendicular to the blade, and the typical widely flared basal cavity. It therefore readily fits within the variation of the populations of the subspecies from Cellon as illustrated by Walliser (1964, Pl. 20, figs 7, 8, 12–16, 19–25) and revised by Klapper & Murphy (1974). This is a broader view of the taxon than utilised by Jeppsson (1989).

Distomodus staurognathoides (Walliser, 1964)
Fig. 6, G, I, M–N.

For synonymy see Simpson (1999: 189) and add the following:

Distomodus staurognathoides (Walliser) – Cockle 1999: 120, pl. 1., fig. 18. – Talent & Mawson 1999: pl. 3, figs 3–4, 9–15: – Rickards et al. 2001: Fig. 2, h–l: – Farrell 2002: Fig. 4, D–F, H, I, K: – Zhang & Barnes 2002: 13–15, Fig. 14.1–14.7.

Remarks. A single Sc element was obtained in this study. Although the ramiform complex of the genus *Distomodus* shows similarities across species, particularly in the symmetry transition series, we consider this element most probably represents *D. staurognathoides* because of the age of the interval. It is almost identical in morphology to that illustrated by Rickards et al. (2001: Fig. 4i.) from the *amorphognathoides* Zone, the latter was recovered with the distinctive platform element.

?Icriodus sp. a Simpson
Fig. 8E.

?*Icriodus* sp. n. A Simpson 1998: 160, pl. 3, figs 12–19.

Remarks. This single element bears strong similarity to Late Silurian elements recovered from the Jack Formation in north Queensland (Simpson 1998). Whilst the element has the typical triangular basal structure typical of Sa elements, this example is slightly asymmetrical and may possibly represent an Sa/Sb transitional form.

Pseudobelodella silurica Armstrong, 1990
Fig. 7, I–J.

For synonymy see Simpson & Talent (1995: 176).

Remarks. The single element is erect with numerous fused apically inclined denticles. It has a close resemblance to the aq element of this taxon. Despite the fact that Armstrong (1990) differentiated this genus from *Belodella* by the presence of the heeled sym p element, the morphology of the single aq element recovered in this study allows identification with some confidence.

Panderodus ?n. sp.
Fig. 8J.

Remarks. The single element described above has a number of distinctive features not typically noted in populations of *Panderodus*. It may therefore represent a new species. It is illustrated and kept in open nomenclature for comparative purposes. Other *Panderodus* elements obtained in this study have not been investigated in detail.

APPENDIX: NOTES ON SAMPLED LOCALITIES

1. This, the most productive for conodonts of the limestone occurrences sampled, outcrops boldly on both flanks of the Mitta Mitta River about 260–320 m upstream from its junction with Wombat Creek (Whitelaw 1954: fig. 2^E). It was interpreted

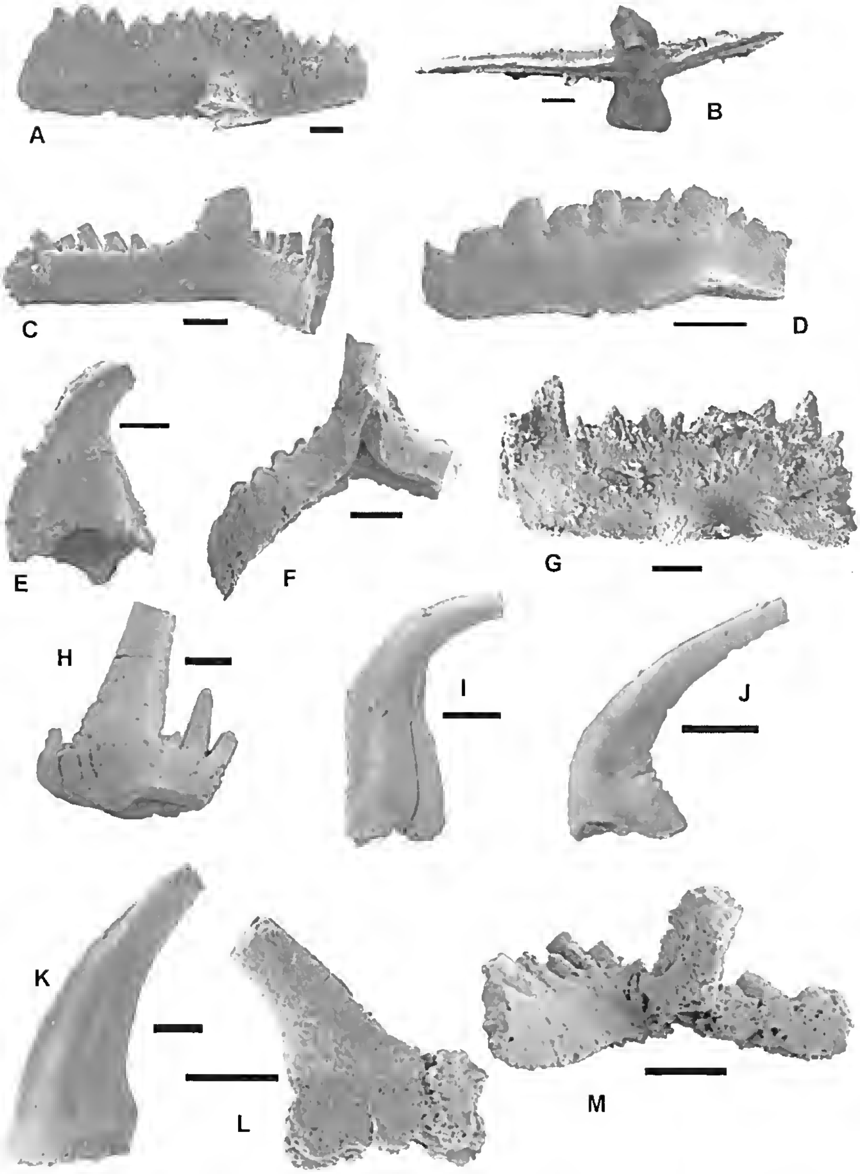


Fig. 8. Late Silurian (late Ludlow to mid-Přidolí) conodonts from Pyle's limestone deposit, 4.5 km north-northeast of Benambra, and Late Silurian conodonts from limestone clasts, "Wibenduck Limestone", Martins Creek-Sardine Creek Saddle, eastern Victoria (for localities see Appendix, Fig. 1, and VandenBerg et al., 1998b, 1992).
A-B. *Ozarkodina martinsoni auriformis* Simpson 2003, Pa element, lateral and lower view respectively of AMF 125154, Loc. 5. C-D. *Ozarkodina excavata excavata* (Branson & Mehl 1933). C. Sc element, inner lateral view of AMF 125155, Loc. 5. D. Pa element, outer lateral view of AMF 125156, Loc. 5. E. ?*Icriodus* sp. a Simpson 1998, Sa/Sb element, posterior view of AMF 125157, Loc. 5. F. *Ozarkodina excavata excavata* (Branson & Mehl 1933), Sa element (incomplete), inner lateral view of AMF 125158, Loc. 5. G. *Ozarkodina remscheidensis eosteinhornensis* (Walliser 1964), Pa element, lateral view of AMF 125159, Loc. 4. H. *Ozarkodina excavata excavata* (Branson & Mehl 1933) fragmentary ?Sb element, inner lateral view of AMF 125160, Loc. 4. I. *Panderodus* sp., lateral view of AMF 125161, Loc. 4. J. *Panderodus* ?n. sp., lateral view of AMF 125162, Loc. 4. K. *Panderodus* sp., lateral view of AMF 125163, Loc. 4. L. Indeterminate fragment, AMF 125164, Loc. 4. M. *Ozarkodina* sp., fragmentary Sb element, AMF 125165, Loc. 4.

(VandenBerg et al. 1998b) as two bodies, one within the Toaks Creek Conglomerate, the other at the boundary between the Toaks Creek Conglomerate and the overlying Gibbo River Siltstone. We prefer Whitelaw's (1954: 26) interpretation that these are outcrops of the same limestone body on opposite sides of the Mitta Mitta River. Our sampled section commenced at the base of the limestone (= Whitelaw 1954, Fig. 2^{E}; = 'Lower Mitta limestone' of VandenBerg et al. 1998a = base of the Gibbo River Siltstone) on the east flank of the Mitta Mitta River arm of Dartmouth Dam at grid reference 5589_{5},59318_{0} on Benambra 1:50,000 sheet 8424-3.

2. Sampled section (11 samples) through Brammall Bluff (Whitelaw 1954, Fig. 3^{B}; = 'Hairpin limestone' of VandenBerg et al. 1998a); interpreted by VandenBerg et al. (1998a) as being in the Undowah Siltstone on the north flank of the Gibbo River commencing at grid reference 5607_{96},59314_{63} on Benambra 1:50,000 sheet 8424-3. The start of the sampled section is 75 m (across strike) above the base of an interval of generally massive, yellow-buff-weathering dolomitic limestone or dolomite. The section extends through 37 m of well-bedded siltstones with slatey carbonates (often iron-rich), thin-bedded rather bioclastic limestones and nodular limestones (subordinate to siltstones), and is followed by a further 25 m with buff- to yellow-weathering dolomitic olistoliths (largest c. 5 m) exhumed from upslope.

3. Spot sample from the southeast end of 'Quart Pot limestone' of VandenBerg et al. (1998a) (= Whitelaw 1954, Fig. 2^{D}) at grid reference 5568_{45},59326_{3} on Benambra 1:50,000 sheet 8424-3. Repeated sampling of the 'Quart Pot limestone' (Whitelaw 1954, figs. 2^{C} and 2^{D}) at grid reference 5565_{5},59327_{5} (limestone with pentamerids) and 5565_{3},59327_{4}, and the nearby 'Toak's Gap limestone' in the vicinity of 5540,5935_{7}, all on Dart 1:50,000 sheet 8424-4, failed to produce conodonts. In both cases contacts with the underlying conglomerates and arenites and with the overlying mudstones are obscured by alluvials or soil.

4. Spot samples from Pyle's limestone deposit (Whitelaw 1954: fig. 3^{D}; Talent et al. 1975; Simpson & Talent 1995; VandenBerg et al. 1998a) at grid reference 5644_{8},59141_{0} on Benambra 1:50,000 sheet 8424-3 where there are poor exposures of metamorphosed calcareous siltstones and arenites with minor thin bands of limestone. This occurrence was interpreted (VandenBerg et al. 1998a: 104) as overlying Pinnak Sandstone (Early Ordovician).

5. Spot samples of "Wibenduck Limestone" from float and from a small quarry outcropping beside the Scanlon Creek Track on Bendoc 1:100,000 sheet 8623 at grid reference 394,557.

6. Samples from the 'Lower Gibbo limestone' (a body we agree with VandenBerg et al. 1998a, is an olistolith) at 5597_{5},59317_{5}, from the 'Silver Flat limestone' in the vicinity of 5612,59308 (several samples), from the counterpart of the 'Lower Mitta limestone' of VandenBerg et al. (1998a; = Whitelaw 1954, Fig. 2^{E}) but on the west flank of the Mitta Mitta River arm of Dartmouth Dam, and from a sampled stratigraphic section through the 'Meanders 3 limestone' of VandenBerg et al. (1998a) in the vicinity of 5592,59292, all on Benambra 1:50,000 sheet 8424-3, also failed to produce conodonts.

7. A superbly exposed limestone and calcareous mudstone sequence (Whitelaw 1954: fig. 2^{F}) outcrops in a cliff on the right flank of the Mitta Mitta River about 3.6 km upstream from its junction with Wombat Creek. It may be as much as 1000 m stratigraphically higher in the Tongaro Siltstone than the 'Lower Mitta limestone', but the possibility of faulting (Fig. 3) between it and the 'Lower Mitta limestone' prevents accurate assessment of the intervening thickness. It too shows very gradual transition from massive through bedded limestone to calcareous mudstones — again a relationship we interpret as indicating a probably autochthonous sequence rather than an olistolith. Unfortunately this occurrence — with tabulate corals including halysitids (Chapman 1920) — has so far failed to produce conodonts.

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REFERENCES

Aldridge, R. J. & Schönlaub, H. J., 1989. Conodonts. In *A global standard for the Silurian System*, 247–279. In C. H. Holland & M. G. Bassett, eds, National Museum of Wales, Geological Series 9. Cardiff.

Allen, R. L., 1987. *Subaqueous volcanism, sedimentation and the geological setting of Zn–Cu–Pb massive sulphide deposits, Benambra, S.E. Australia*, 284 p. Ph.D. thesis, Department of Earth Sciences, Monash University, Melbourne.

Allen, R. L., 1988. Limestone Creek Graben. In *Geology of Victoria*, 92. In J. G. Douglas & J. A. Ferguson, eds, Victorian Division, Geological Society of Australia Inc.

Allen, R. L., 1991. *Limestone Creek area 1:50 000 geological map, edition 2*. Geological Survey of Victoria, Melbourne.

Allen, R. L., 1992. Reconstruction of the tectonic, volcanic, and sedimentary setting of strongly deformed Zn–Cu massive sulfide deposits at Benambra, Victoria. *Economic Geology* 87: 825–854.

Andrews, E. C., 1938. The structural history of Australia during the Palaeozoic. (The stabilization of a continent). *Journal and Proceedings of the Royal Society of New South Wales* 71: 118–187.

Armstrong, H. A., 1990. Conodonts from the Upper Ordovician–Lower Silurian carbonate platform of north Greenland. *Grønlands Geologiske Undersøgelse* 159: 1–151.

Barca, S., Ferretti, A., Massa, P. & Serpagli, E., 1992. The Hercynian Arburese tectonic unit of SW Sardinia new stratigraphic unit and structural data. *Rivista Italiana di Paleontologia i Stratigrafia* 98 (2): 119–136.

Birch, W. D., Henry, D. A. & Pring, A., 1995. A new occurrence of Mrazekite from Benambra, Victoria, Australia. *The Mineralogical Record* 26: 107–113.

Bischoff, G. C. O., 1986. Early and Middle Silurian conodonts from midwestern New South Wales. *Courier Forschungsinstitut Senckenberg* 89: 1–337.

Bolger, P., 1982. Ordovician and Silurian stratigraphy and structure in the Wombat Creek–Benambra area, northeast Victoria. *Proceedings of the Royal Society of Victoria* 94: 35–47.

Brime, C., Talent, J. A. & Mawson, R., 2003. Low grade metamorphism in the Palaeozoic sequences of the Townsville hinterland of northeastern Australia. *Australian Journal of Earth Sciences* 50: 751–767.

Browne, W. R., 1947. A short history of the Tasman Geosyncline of eastern Australia. *Science Progress* 140: 623–637.

Calner, M. & Jeppsson, L., 2003. Carbonate platform evolution and conodont stratigraphy during the Middle Silurian Mulde Event, Gotland, Sweden. *Geological Magazine* 140: 173–203.

Carey, S. P. & Bolger, P. F., 1995. Conodonts of disparate Lower Devonian zones, Wilson Creek Shale, Tyers–Walhalla area, Victoria, Australia. *Alcheringa* 19: 73–86.

Chapman, F., 1912. Reports on fossils. Silurian and Devonian fossils from the Mitta Mitta district, northeast Victoria. *Records of the Geological Survey of Victoria* 3: 215–217.

Chapman, F., 1920. Palaeozoic fossils of eastern Victoria. Part IV. *Records of the Geological Survey of Victoria* 4: 175–194.

Cockle, P., 1999. Conodont data in relation to time, space and environmental relationships in the Silurian (Late Llandovery–Ludlow) succession at Boree Creek (New South Wales, Australia). *Abhandlungen der Geologischen Bundesanstalt* 54: 107–133.

Collins, W. J., & Hobbs, B.E., 2001, What caused the Early Silurian change from mafic to silicic (S-type) magmatism in the eastern Lachlan Fold Belt? *Australian Journal of Earth Sciences* 48: 25–51.

Colquhoun, G. P. 1995. Early Devonian conodont faunas from the Capertee High, NE Lachlan Fold Belt, southeastern Australia. *Courier Forschungsinstitut Senckenberg* 182: 347–369.

Conaghan, P. J., Mountjoy, E. W., Edgecombe, D. R., Talent, J. A. & Owen, D. E., 1976. Nubrigyn algal reefs (Devonian), eastern Australia: Allochthonous blocks and megabreccias. *Geological Society of America Bulletin* 87: 515–530.

Cooper, B. J., 1977. Preliminary report on conodonts from the Wombat Creek Group,

north-eastern Vietoria. *South Australian Department of Mines Report* 77/139 (unpublished).

Corradini, C., Ferretti, A., Serpagli, E. & Barca, S., 1998. The Ludlow–Pridoli seetion Genna Ciuereiu, west of Silius. *Giornale di Geologia*, series 3a, 60, Speeial Issue, ECOS VII–Sardinia Guide Book, 112–118.

Corradini, C. & Serpagli, E., 1999. A Silurian eonodont biozonation from late Llandovery to end Přídolí in Sardinia (Italy). *Bolletino della Società Paleontologica Italiana* 37(2–3): 255–273.

Crook, K. A. W., Bein, J., Hughes, R. J. & Scott, P. A., 1973. Ordovieian and Silurian history of the southeastern part of the Lachlan Geosyneline. *Journal of the Geologieal Society of Australia* 20: 113–138.

Epstein, A. G., Epstein, J. B., & Harris, L. D., 1977. Conodont Colour Alteration — an index to organie metamorphism. *United States Geological Survey Professional Paper* 995: 1–27.

Eriksson, M., 2001. Silurian ramphoprionid polyehaetes from Gotland, Sweden. *Journal of Paleontology* 75: 993–1015.

Farrell, J. R., 2002. Reworked Silurian and Ordovician eonodonts from the Late Devonian Catombal Group, eentral western New South Wales. *Alcheringa* 26: 37–48.

Ferguson, W. H., 1899. Report on eollection of fossils, ete., from Wombat Creek. *Geologieal Survey of Vietoria Monthly Progress Report* 3: 17.

Ferretti, A., Corradini, C., & Serpagli, E., 1998. Wenloek–Ludlow eonodonts from Perd'e Fogu (Fluminimaggiore). *Giornale di Geologia*, series 3a, 60, Special Issue, ECOS VII–Sardinia Guide Book, 156–167.

Foster, D. A. & Gray, D. R., 2000. The strueture and evolution of the Laehlan Fold Belt (Orogen) of eastern Australia. *Annual Review of Earth and Planetary Seienees* 28: 47–80.

Foster, D. A., Gray, D. R. & Bucher, M., 1999. Chronology of deformation within the turbidite-dominated Laehlan Orogen: implications for the teetonie evolution of eastern Australia and Gondwana. *Tectonics* 18: 452–485.

Foster, D. A., Gray, D. R. & VandenBerg, A. H. M., 2000. Diseussion and Reply: Timing of orogenie events in the Laehlan Orogen. *Australian Journal of Earth Seienees* 47: 813–822.

Furey-Greig, T., 1995. The "Nemingha" and "Loomberah" limestones (Early Devonian; Emsian) of the Nemingha–Nundle area, northern New South Wales: eonodont data and inferred environments. *Courier Forschungsinstitut Senckenberg* 182, 217–233.

Gray, D. R. & Foster, D. A., 1997. Orogenie eoneepts — applieation and definition: Laehlan Fold Belt, eastern Australia. *Ameriean Journal of Science* 297: 859–891.

Gray, D. R. & Foster, D. A., 1998. Charaeter and kinematies of faults within the turbidite-dominated Laehlan Orogen: implieations for the tectonie evolution of eastern Australia. *Journal of Strnctural Geology* 20: 1691–1720.

Gray, D. R. & Foster, D. A., 1999. Charaeter and kinematies of faults within the turbidite-dominated Laehlan Orogen: implieations for the teetonie evolution of eastern Australia: Reply. *Journal of Struetural Geology* 22: 1529–1535.

Gray, D. R., Foster, D. A. & Bucher M., 1997. Reeognition and definition of orogenie events in the Laehlan Fold Belt. *Australian Journal of Earth Seienees* 44: 489–581.

Harris, A. G. 1979. Conodont eolor alteration, and organo-mineral metamorphic index, and its applieation to Appalachian Basin geology. In *Aspects of diagenesis*, P. A. Seholle & P. R. Schluger, eds, *Soeiety of Eeonomie Paleontologists and Mineralogists, Special Publication* 26: 3–16.

Harris, A. G. 1981. Color and alteration: an index to organic metamorphism in eonodont elements, W56–W60. In: Clark D. L. and 10 others, *Treatise on Invertebrate Paleontology, Part W, Miseellanea, Supplement* 2, Conodonta. Geologieal Soeiety of Ameriea, Boulder, and University of Kansas, Lawrenee.

Jeppsson, L., 1989. Latest Silurian conodonts from Klonk. *Geologiea et Palaeontologiea* 23: 21–37.

Jeppsson, L., 1997. A new latest Telyehian, Sheinwoodian and Early Homerian (Early Silurian) Standard Conodont Zonation.

Transactions of the Royal Society of Edinburgh, Earth Sciences 88: 91–114.

Klapper, G. & Murphy, M. A., 1974. Silurian–Lower Devonian conodont sequence in the Roberts Mountains Formation of central Nevada. *University of California Publications in the Geological Sciences* 115: 62 pp., 12 pls.

Link, A. & Druce, E. C., 1972. Ludlovian and Gedinnian conodont biostratigraphy of the Yass Basin, New South Wales. *Bulletin of the Bureau of Mineral Resources, Geology and Geophysics* 134: 136 pp, 12 pls.

Männik, P., 1998. Evolution and taxonomy of the Silurian conodont *Pterospathodus*. *Palaeontology* 41: 1001–1050.

Männik, P. & Aldridge, R. J., 1989. Evolution, taxonomy and relationships of the Silurian conodont *Pterospathodus*. *Palaeontology* 32: 893–906.

Mawson, R., Molloy, P. D., Simpson, A. J. & Talent, J. A., 2003. Latest Silurian and Early Devonian conodonts from Nowshera, NWFP, Pakistan. *Courier Forschungsinstitut Senckenberg* 245: 83–105.

Mawson, R., Pang, D. & Talent, J. A., 1998. G. J. Hinde's (1899) Devonian radiolarians from the Tamworth area, north-eastern New South Wales: stratigraphic and chronologic context. *Proceedings of the Royal Society of Victoria* 109: 233–256.

Mawson, R. & Talent, J. A., 1994. Age of an Early Devonian carbonate fan and isolated limestone clasts and megaclasts, east-central Victoria. *Proceedings of the Royal Society of Victoria* 106: 31–70.

Meinert, L. D., 1992. Skarns and skarn deposits. *Geoscience Canada* 19: 145–152.

Miller, C. G. 1995. Ostracode and conodont distribution across the Ludlow/Přídolí boundary of Wales and the Welsh Borderland. *Palaeontology* 38: 341–384.

Packham, G. H. (ed.) 1969. The geology of New South Wales. *Journal of the Geological Society of New South Wales* 16: 1–654.

Packham, G. H., Percival, I. G. & Bischoff, G. C. O. 1999. Age constraints on strata enclosing the Cadia and Junction Reefs ore deposits of central New South Wales, and tectonic implications. *Quarterly Notes of the Geological Survey of New South Wales* 110: 1–12.

Percival, I.G., 1998. The age of the Nandillyan and Narragal limestones, Molong High, central western New South Wales. *Geological Survey of New South Wales, Quarterly Notes* 107: 12–19.

Ramsay, W. R. H. & VandenBerg, A. H. M., 1986. Metallogeny and tectonic development of the Tasman Fold Belt System in Victoria. *Ore Geology Reviews* 1: 213–257.

Reed, A. R., 2001. Pre-Tabberabberan deformation in eastern Tasmania: a southern extension of the Benambran Orogeny. *Australian Journal of Earth Sciences* 48: 785–796.

Rejebian, V. A., Harris, A.G. & Huebner, J. S., 1987. Conodont colour and textural alteration: An index to regional metamorphism. *Geological Society of America Bulletin* 99: 471–479.

Rickards, R. B., Percival, I. G., Simpson, A. J. & Wright, A. J., 2001. Silurian biostratigraphy of the Cadia area, south of Orange, New South Wales. *Proceedings of the Linnean Society of New South Wales* 123: 173–191.

Scheibner, E. 1997. Geology of New South Wales — synthesis. Vol. 2, Geological evolution, 666 p. New South Wales Department of Mineral Resources, Sydney.

Serpagli, E., Corradini, C. & Ferretti, A., 1998. Conodonts from a Ludlow–Pridoli section near the Silius village. *Giornale di Geologia*, series 3a, 60, Special Issue, ECOS VII-Sardinia Guide Book, 104–111.

Simpson, A. J., 1998. Apparatus structure of the latest Silurian to early Devonian conodont *Icriodus woschmidti hesperius* Klapper et Murphy, and some comments on phylogeny. *Palaeontologia Polonica* 58: 153–169.

Simpson, A. J., 1999. Early Silurian conodonts from the Quinton Formation of the Broken River region, (north-eastern Australia). *Abhandlungen der Geologischen Bundesanstalt* 54: 181–199.

Simpson, A. 2003. A new subspecies of the conodont genus *Ozarkodina* and its correlative value. *Courier Forschungsinstitut Senckenberg* 245: 75–82.

Simpson, A. J., Bell, K. N., Mawson, R., & Talent, J. A., 1993. Conodonts and foraminifers from the late Ludlow (Late Silurian) at Cowombat, south-eastern Australia. *Aus-*

tralasian Association of Palaeontologists, Memoir 15: 141–159.

Simpson, A. J. & Talent, J. A., 1995. Silurian conodonts from the headwaters of the Indi (upper Murray) and Buchan rivers, southeastern Australia, and their implications. *Courier Forschungsinstitut Senckenberg* 182: 79–215.

Simpson, A. J., & Talent, J. A., 1996. Middle Palaeozoic orogenic events in the southern Lachlan Fold Belt: age constraints from conodont data. *Geological Society of Australia Abstracts* 41: 396.

Sloan, T. R., Talent, J. A., Mawson, R., Simpson, A. J., Brock, G. A., Engelbretsen, M. J., Jell, J. S., Aung, A. K., Pfaffenritter, C., Trotter, J. & Withnall, I. W., 1995. Conodont data from Silurian–Middle Devonian carbonate fans, debris flows, allochthonous blocks and adjacent autochthonous platform margins: Broken River and Camel Creek areas, north Queensland, Australia. *Courier Forschungsinstitut Senckenberg* 182: 1–77.

Stirling, J., 1887. Second progress report on preliminary geological traverse of the western boundary of the County of Benambra. *Quarterly Reports of the Mining Registrars for the Quarter ended December 1887, Department of Mines, Victoria*, 75–77.

Stirling, J., 1888a. Geological structure of the country between Orbost and Hutton's Camp, on the Yalma Creek. *Mining Regulations Report, Quarter ending 31 March 1888, Geological Survey, Victoria*, 87–88.

Stirling, J., 1888b. Appendix D. Preliminary notes on the geology of the Wombat Creek valley, its caves and silver lodes. *Reports of the Mining Surveyors and Registrars, Quarter ending 30th September 1888, Department of Mines, Victoria*,78–80.

Talent, J. A., 1959. Notes on Middle Palaeozoic stratigraphy and diastrophism in eastern Victoria. *Mining and Geological Journal (Victoria)* 6 (3): 57–58.

Talent, J. A., Berry, W. B. N. & Boucot, A. J., 1975, Correlation of the Silurian rocks of Australia, New Guinea and New Zealand. *Geological Society of America Special* Paper 150: 108 pp.

Talent, J. A. & Mawson, R., 1999. North-eastern Molong Arch and adjacent Hill End Trough (eastern Australia): Mid-Palaeozoic conodont data and implications. *Abhandlungen der Geologischen Bundesanstalt* 54: 49–105.

Talent, J. A., Mawson, R. & Simpson, A. J., 2003a. Silurian of Australia and New Guinea. In *Silurian Lands and Seas — Paleogeography outside of Laurentia*, E. Landing & M. E. Johnson, eds, *New York State Museum Bulletin* 493: 181–220.

Talent, J. A., Mawson, R. & Simpson, A. J., 2003b. The "lost" Early Ordovician–Devonian Georgetown Carbonate Platform of northeastern Australia. *Courier Forschungsinstitut Senckenberg* 242: 71–79.

Talent, J. A., Mawson, R., Simpson, A. J. & Brock, G. A., 2002. Ordovician–Carboniferous of the Townsville Hinterland: Broken River and Camel Creek regions, Burdekin and Clarke River Basins. Macquarie University Centre for Ecostratigraphy and Palaeobiology Special Publication 1: 82 pp.

Taylor, C. D., 1984. Structure and stratigraphy of the Yalmy Creek area, 41 pp. BSc (Hons) dissertation, Department of Earth Sciences, Melbourne University.

Thomas, D. E., 1954. Foreward [to Whitelaw, H. S., 1954, q.v.]. *Mining and Geological Journal (Victoria)* 5 (3): 23.

VandenBerg, A. H. M., 1988. Silurian–Middle Devonian. In *Geology of Victoria*, J. G. Douglas & J. A. Ferguson, eds, Geological Society of Australia, Victorian Division, Melbourne, 103–146.

VandenBerg,A. H. M., 1999. Timing of orogenic events in the Lachlan Orogen. *Australian Journal of Earth Sciences* 46: 691–701.

VandenBerg, A. H. M., Bolger, P. F. & O'Shea, P. J., 1984. Geology and mineral exploration of the Limestone Creek area, northeast Victoria. *Geological Survey Report, Department of Minerals and Energy Victoria* 72, 59 pp.

VandenBerg, A. H. M., Hendrickx, M. A., Willman, C. E., Magart, A. P. M., Simons, B. A, & Ryan, S. M., 1998a. Benambra 1:100 000 map area geological report. *Geological Survey Report, Department of Natural Resources and Environment Victoria*, 114, 279 pp.

VandenBerg, A. H. M., Magart, A. P. M., Simons, B. A., Willman, C. E. & Hendrickx, M. A., 1998b. 1:50 000 geological map,

Benambra 8424-3. *Geological Survey of Victoria. Department of Natural Resources and Environment Victoria.*

VandenBerg, A. H. M., Nott, R. J. & Glen, R. A., 1992. Bendoc 1:100, 000 Map Geological Report. *Geological Survey Report, Department of Energy & Minerals, Victoria* 90, 121 pp.

VandenBerg, A. H. M., Willman, C. E., Maher, S., Simons, B. A., Cayley, R. A., Taylor, D. H., Morand, V. J., Moore, D. H. & Radkovic, A. 2000. *The Tasman Fold Belt system in Victoria*, 492 p. Geological Survey of Victoria, Special Publication, Melbourne.

Walliser, O.H., 1964. Conodonten des Silurs. *Abhandlungen des hessischen Landesamtes für Bodenforschung* 41, 1–106.

Walley, A. M., Strusz, D.L. & Yeates, A. N., 1990. *Palaeogeographic Atlas of Australia, vol. 3, Silurian.* Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia, 27 pp.

Whitelaw, H. S., 1954. Some limestone and marble deposits of east Gippsland. *Mining and Geological Journal (Victoria)* 5 (3): 23–33.

Willman, C. E., Morand, V. J., Hendrickx, M. A., VandenBerg, A. H. M., Haydon, S. J. & Carney, C., 1999. The geology and prospectivity of the Omeo 1:100 000 map area, eastern Victoria. *Geological Survey Report, Department of Natural Resources and Environment Victoria* 118 pp.

Zhang, S. & Barnes, C. R., 2002. A new Llandovery (Early Silurian) conodont biozonation and conodonts from the Becscie, Merrimack, and Gun River formations, Anticosti Island, Quebec. *Journal of Paleontology 76, (Supplement to No 2; Paleontological Society Memoir 57)*, 46 pp.

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A NEW FOSSIL CONIFER, *BELLARINEA RICHARDSII*, FROM THE EARLY CRETACEOUS STRZELECKI GROUP, SOUTHEASTERN VICTORIA

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NAGALINGUM, NATHALIE S., DRINNAN, ANDREW N. & MCLOUGHLIN, STEPHEN 2005. A new fossil conifer, *Bellarinea richardsii*, from the Early Cretaceous Strzelecki Group, southeastern Victoria. *Proceedings of the Royal Society of Victoria* 117(2): 295–306 ISSN 0035-9211.

A new species of fossil conifer foliage, *Bellarinea richardsii*, is described and illustrated from Neocomian (Early Cretaceous) sediments of the Tyers River Subgroup in south-eastern Victoria. The specimens consist of intact seasonal shoots and isolated leaves, and their depositional setting in prominent leaf mats suggests a seasonal, deciduous habit. Individual leaves are spirally inserted on the shoot axis but the leaf bases are twisted to lie on a common plane giving the shoots plagiotropic symmetry. Although lacking attached reproductive structures the gross morphology and cuticular details of the shoots and leaves suggests assignment to either Podocarpaceae or Taxodiaceae. This species and a range of comparable forms represent a prominent component of Australian mid-Mesozoic floras.

Keywords: Palaeobotany, conifer, Early Cretaceous, Strzelecki Group

MESOZOIC FLORAS have been known from Victoria since the pioneering work of McCoy (1874, 1875). Early reports assigned much of this material to the Jurassic (McCoy 1860, 1875, Seward 1904), but for the last 40 years it has been recognized that this component is Early Cretaceous in age (Dettmann 1963, Douglas 1969, 1973). Victorian Cretaceous floras are of interest because the forests that they represent grew at high southern latitudes, experienced conditions unlike any that exist in the world today, and were home to a diverse biota including polar dinosaurs (Rich et al. 1988).

Conifers represented an important component of floras throughout the Victorian Early Cretaceous. Assemblages assigned to Douglas' (1969) Zone A (=*Ptilophyllum spinosum-P. castertonensis* Zone: latest Jurassic? to early Neocomian) are known only from bore cores in the Otway Basin and their conifer remains have not been studied in detail. Assemblages referable to Douglas' Zone B (=*Phyllopteroides laevis* Zone of Cantrill & Webb 1987: Neocomian) are recorded from the Boola Boola Forest of Gippsland, small areas on the Mornington Peninsula and Philip Island and from the subsurface of the western Otway Basin. Rich plant assemblages from these beds have recently been described by McLoughlin et al. (2002). Assemblages assigned to Douglas' Zone C (roughly equivalent to the *Phyllopteroides serrata* Zone of Cantrill & Webb 1987: Barremian to earliest Albian) are widely represented in the Gippsland and Otway basins. Several taxa of coniferous foliage have been described from this zone including *Bellarinea barklyi* Florin, *Elatocladus mccoyi* Florin, *Elatocladus* sp., *Podozamites ellipticus* McCoy, *Brachyphyllum gippslandicum* McCoy, *Araucaria* sp. cf. *A. heterophylla* (Salisbury) Franco, and a range of cones, cone scales, and seeds mostly with inferred araucarian or podocarpacean affinities (McCoy 1874, Florin 1952, Drinnan & Chambers 1986). Douglas' Zone D (roughly equivalent to the *Phyllopteroides dentata* Zone of Cantrill & Webb 1987: Albian) assemblages are confined to the Otway Basin and are rich in conifers. Cantrill & Douglas (1988) and Cantrill (1991, 1992) documented the leaf morphology, cuticular features and phylogenetic affinities of five species ascribed to *Araucaria*, one to *Agathis*, and several broad-leafed forms assigned to the form-genus *Podozamites*. Cantrill (1991) suggested that the *Podozamites* species were possibly representatives of Podocarpaceae or Araucariaceae, and Pole (1995) later transferred *Podozamites taenioides to Araucarioides*. Cantrill & Douglas (1988) erected *Geinitzia tetragona* for conifer foliage associated with roots bearing mycorrhizal nodules and suggested a taxodiaceous affinity for this species, but Pole (2000) considered the cuticular micromorphology to be indicative of a cheirolepidiaceous affinity and transferred this species to the new genus *Otwayia*.

Assemblages representative of the *Phyllopteroides laevis* Zone (Douglas' Zone B) are best

expressed in exposures of the Tyers River Subgroup in the Boola Boola Forest north-northwest of Traralgon (Fig. 1A). This zone is notable for its abundance of small-leaved bennettitaleans (*Otozamites*) and several other pteridosperm taxa [*Taeniopteris daintreei* McCoy, *Rintoulia variabilis* (Douglas) McLoughlin & Nagalingum in McLoughlin et al. (2002), *Komlopteris indica* (Feistmantel) Barbacka and *Pachydermophyllum austropapillosum* (Douglas) McLoughlin & Nagalingum in McLoughlin et al. (2002)], which most likely represented the principal mid-storey elements of the vegetation. Associated with these pteridosperm leaves in the Boola Boola assemblages are abundant conifer leaves belonging to plants that probably constituted the upper stratum of these Early Cretaceous forests. Three principal conifer species are represented: *Brachyphyllum tyersensis* Tosolini & Nagalingum (in McLoughlin et al. 2002), *Otwayia hermata* Tosolini & Nagalingum (in McLoughlin et al. 2002) and a new species of Bellarinea, that is the basis of this paper.

GEOLOGICAL SETTING

The Boola Boola Forest is located approximately 12 km north-northwest of Traralgon, Gippsland (Fig. 1A). The rocks exposed in this area represent the northernmost extent of Cretaceous sediments in the Gippsland Basin and they rest on Lower Devonian metasedimentary rocks with an angular unconformity of considerable relief. They are separated from Cretaceous exposures of the South Gippsland Highlands by Cenozoic sediments in the Latrobe Valley Depression. Lower Cretaceous rocks of the Gippsland Basin have been assigned in their entirety to the Strzelecki Group (Douglas 1988). The upper part of the succession is dominated by feldspathic sandstones and has been assigned to the 'Wonthaggi Formation' by Constantine & Holdgate (1993). The lower part of the succession, assigned to the Tyers River Subgroup and principally exposed in the Boola Boola Forest area, is dominated by conglomerates and quartzose or lithic sandstones. The Tyers River Subgroup incorporates the Tyers Conglomerate (c. 120 m thick) and Rintoul Creek Formation (c. 480 m thick) in ascending order (Tosolini et al. 1999). The Rintoul Creek Formation has been further subdivided into a lower unit (Locmany Member) of mixed lithologies and an upper unit (Exalt Member) dominated by thick sandstone packages. The Tyers Conglomerate is interpreted to represent alluvial fan and proximal braided river deposits whereas the succeeding Rintoul Creek Formation represents mixed braided and meandering river deposits in alluvial valley settings (Tosolini et al. 1999). The material used in this study is from the lower part of the type section of the Rintoul Creek Formation (Locmany Member), approximately 160 m above the base of the unit. Biostratigraphic studies of the sampled beds have assigned these rocks to the *Foraminisporis wonthaggiensis* palynozone (Dettmann 1963, Helby et al. 1987), *Phyllopteroides laevis* macrofloral zone (Cantrill & Webb 1987), and the *Trikonia locmaniensis* megaspore zone (Tosolini et al. 2002) of Neocomian age (Fig. 1B).

MATERIAL AND METHODS

Specimens used in this study were collected over a period of 35 years from the mid-1960s by Dr. J. Douglas (formerly of the Geological Survey of Victoria) and the present authors. The material is derived from several localities in the Boola Boola State Forest, 12 km NNW of Traralgon, Victoria (Fig. 1A). Cuticles were prepared by oxidation in Schultze's solution (nitric acid with dissolved potassium chloride crystals) for up to one hour to remove coalified mesophyll tissues. Slight heating (up to 45°C) and further treatment with 5% sodium hydroxide or 5% ammonia for up to 15 minutes was undertaken in an attempt to clean the cuticle. Despite varied chemical treatments and heating, *B. richardsii* cuticle proved difficult to recover. It is thin and readily fragmented. In most cases, the best detail of the external surface was obtained by scanning electron microscopy of unoxidized leaves (Fig. 2H, I). Recovery of cuticle after oxidation of the coalified mesophyll did not yield fragments large enough to provide significant details of the cuticle's inner surface morphology. Material for scanning electron microscopy was air-dried, attached to stubs using double sided carbon stickers, and sputter coated with gold. All measurements of epidermal features are from dried specimens. Specimens with the prefix MVP are registered with Museum Victoria, Melbourne.

SYSTEMATIC PALAEOBOTANY

Phylum Coniferophyta
Class Coniferopsida
Order Coniferales

Genus **Bellarinea** Florin 1952 emend.

Type species: *Bellarinea barklyi* Florin 1952; Eumeralla Formation; Aptian; Bellarine Peninsula near Geelong, Victoria, Australia.

Emended diagnosis. As per Florin (1952), but deciduous determinate shoots without branches or terminal resting buds.

Florin (1952) erected *Bellarinea* for shoots with essentially identical gross architecture to those of *Elatocladus* but where cuticular features revealed that the leaves were hypostomatic with haplocheilic stomata arranged in a band on each side of the midvein. Florin's specimens came from Aptian sediments in southern Victoria, and his two species remain the only ones attributed to this genus until this study. *Elatocladus* was erected by Halle (1913) to encompass sterile coniferous shoots of uncertain affinity with spiral phyllotaxy, including those with leaf bases twisted to give a plagiotropic orientation. Halle included in the genus three species from the mid-Mesozoic of India, which he considered identical to the specimens he was describing from the Jurassic Hope Bay locality in west Antarctica. Harris (1979) later emended the diagnosis of *Elatocladus* to incorporate only coniferous shoots that bear linear, univeined leaves that diverge from the stem and are flattened to lie in the same plane. Although this restricted to some extent the morphological scope of the form-genus, it is still sufficiently broad to encompass foliage as different as the rhythmically dimorphic shoots of *Sequoia* (Taxodiaceae), *Cephalotaxus* (Cephalotaxaceae) and *Prumnopitys* (Podocarpaceae), and the seasonally deciduous shoots of *Taxodium* and *Metasequoia* (Taxodiaceae). Unfortunately, Halle's type species, *Elatocladus heterophyllus*, is quite different to most other species of the genus, which have long, narrow, bifacial leaves that are twisted to give the shoot a plagiotropic symmetry. Harris' incorporation of a suite of species from the Jurassic of Yorkshire also substantially expanded the geographical extent of the genus, which was originally Gondwanan. Florin and Harris clearly had different approaches to the use of generic names. Florin preferred smaller genera that were restricted in morphology, and he instituted new genera whenever features were available; Harris preferred broadly circumscribed form-genera and in fact synonomized several of Florin's genera into *Elatocladus* (including one Florin had named for Harris ("*Tomharrisia*"). The reason for our choice of an emended *Bellarinea* in preference to *Elatocladus* is to make the distinction between deciduous shoots (*Bellarinea*) and persistent shoots with rhythmic growth (most *Elatocladus*).

Some Gondwanan Mesozoic conifers with plagiotropic shoots similar to *Bellarinea* and *Elatocladus* have been included in the genera *Mataia* and *Rissikia*. *Mataia* was erected by Townrow (1967) for Jurassic podocarpaceous remains from New Zealand and northeastern Australia. It incorporates shoots bearing hypostomatic to weakly amphistomatic leaves with contracted bases in pseudodistichous arrangement but the genus is defined mainly on reproductive characters that are unavailable for most species of *Bellarinea* and *Elatocladus*. *Rissikia* leaves are rhombic in section with a band of stomates located on each flank. This genus is further differentiated from *Bellarinea* and *Elatocladus* by the presence of small, spirally arranged, scale-like leaves at the base of the shoot proceeded by larger leaves generally in pseudodistichous arrangement. *Rissikia* species are mostly represented in the Triassic of Gondwana and have probable podocarpaceous affinities (Townrow 1967, Anderson & Anderson 1985).

Bellarinea richardsii sp. nov.
Fig. 2A-I

?1958 *Elatocladus* sp. cf. *E. confertus* Halle – Philip, p. 192.
?1958 *Elatocladus mccoyi* Florin – Philip, p. 192.
1969 *Elatocladus* sp. 'a' – Douglas, p. 265.
cf. 1969 *Elatocladus* sp. 'b' – Douglas, p. 90, pl. 9, fig. 2.
1986 *Rissikia* sp. – White, pp. 176, 185, figs 268, 284.
1994 *Elatocladus* sp. – Douglas, p. 178, fig. 9.6a.

Holotype. MVP209942.

Paratypes. MVP209943-209957.

Type locality. Loc. L14 of Douglas (1969), near Exalt Creek, Boola Boola State Forest, central Gippsland, Victoria (Australian Map Grid reference DT045457,578132).

Type formation and age. Loemany Member, Rintoul Creek Formation, Tyers River Subgroup, Strzelecki Group; *Phyllopteroides laevis* macrofloral zone (Cantrill & Webb 1987); Neocomian.

Etymology. After Dr Max Richards, former board member of the CSIRO and chair of the University of Melbourne, School of Botany Foundation.

Diagnosis. Determinate axes bearing up to 45 spirally inserted leaves that are twisted at the base into a pseudo-distichous arrangement. Leaves are univeined, linear to inflexed falcate. Leaf apices are obtuse, commonly possessing a mucronate tip; leaf bases are decurrent. Leaf density is 4–10 per 10 mm. Epidermal cells are rectangular with straight walls. Stomates surrounded by 4–6 papillate subsidiary cells.

DESCRIPTION

Gross morphology. Coniferous shoots up to 84 mm long, consisting of an unbranched, determinate axis bearing up to 45 leaves diverging at 40°-90° to the axis. Leaves are spirally inserted on the axis, but the leaf bases are twisted to give the appearance of a distichous arrangement. The leaves are linear to inflexed-falcate, <16 mm long (typically 5–10 mm) and 0.5–2 mm wide (average 1 mm). Leaf apices are obtuse and commonly mucronate, leaf bases are decurrent, and leaf margins entire. Adjacent margins of leaves on the same side of a shoot are 0.5–4 mm apart, leaf density is 4–10 leaves per 10 mm and the leaves very rarely overlap. The leaves have a midvein that extends into the mucronate tip.

Foliar micromorphology. Epidermal cells are more or less rectangular, and orientated along the axis of the leaf forming a brick-like pattern (Fig. 2H, I). The leaf surface has an uneven or slightly verrucate texture due to bulging of the periclinal walls of epidermal cells. Stomates are arranged in two longitudinal bands on the abaxial leaf surface. Stomatal pores are 26–34 μm long and are surrounded by 4–6 weakly developed, roughly circular papillae or lobes that are 9 μm in diameter.

Distribution. Localities L1, L4, L8, L14, L20, L23, L24, L28, L30 (see Douglas 1969 for details); Localities LC1, LC3, RC17B, RC17C, RC17D, RC20A (see McLoughlin et al. 2002 for details); Tyers River Subgroup (Neocomian), Gippsland Basin, Victoria.

COMPARISON AND REMARKS

Morphology. There is considerable variation in leaf dimensions and orientation among the specimens of *B. richardsii*, however, all have a broadly similar architecture consisting of shoots bearing bifacial, univeined leaves with decurrent, twisted, but unconstricted bases. In a few impressions the leaf bases appear to be contracted but this is due to twisting. Most leaves of *Bellarinea richardsii* are 1 mm wide, linear or very slightly falcate and 2 mm apart. This 'typical' condition was found in over 50 specimens in the Boola Boola fossil flora (Fig. 2A, D, E, F, G). There are several specimens with smaller (1.5–4 mm long) and more closely spaced leaves (10 leaves per 10 mm) but the shoots exhibit the same gross morphology as the 'typical' specimens and are possibly immature or under-developed shoots. Two other unusual specimens have inflexed falcate leaves that are spaced at 4 per 10 mm along the shoot (Fig. 2B), compared to 6–8 leaves per 10 mm in the 'typical' shoots. The range of leaf arching may vary considerably along a single shoot. In many cases, strongly curved leaves are also relatively narrow (Fig. 2B). The margins of extant *Metasequoia glyptostroboides* leaves become recurved with desiccation and this process may have been responsible for the arching, twisting and enrollment of some *B. richardsii* leaves.

Complete shoots of *Bellarinea richardsii* are preserved in densely matted accumulations, which is suggestive of a deciduous habit. The slender axes bear leaves of nearly uniform length supporting the hypothesis that the fossils represent detached short shoots of a single season's growth. The leaves along some shoots of *B. richardsii* decrease in length distally (Fig. 2C), but the general condition is with leaves of roughly the same length along the entire shoot. They are similar in appearance to the seasonally abscised shoots of extant *Taxodium distichum* (L.) Richard. However, detached *Bellarinea*-like leaves are also very common in the Boola Boola sediments suggesting that at least some were shed before the shoots abscised. This latter style of foliar detachment is similar to that of extant *Metasequoia glyptostroboides* Miki ex Hu & W.C. Cheng, which often sheds many of its leaves before the shoots. There is no evidence of branching on any of the shoots and none of the specimens possesses axillary or terminal buds. This favours the interpretation that the shoots were seasonally shed units.

Affinities. The systematic affinities of *Bellarinea richardsii* are unclear due to the lack of attached reproductive organs and the difficulty in obtaining definitive cuticular characters. Pollen from several conifer families occurs in the Tyers River Subgroup (Dettmann 1963). Araucariaceae is represented by the pollen *Araucariacites australis* Cookson ex Couper.

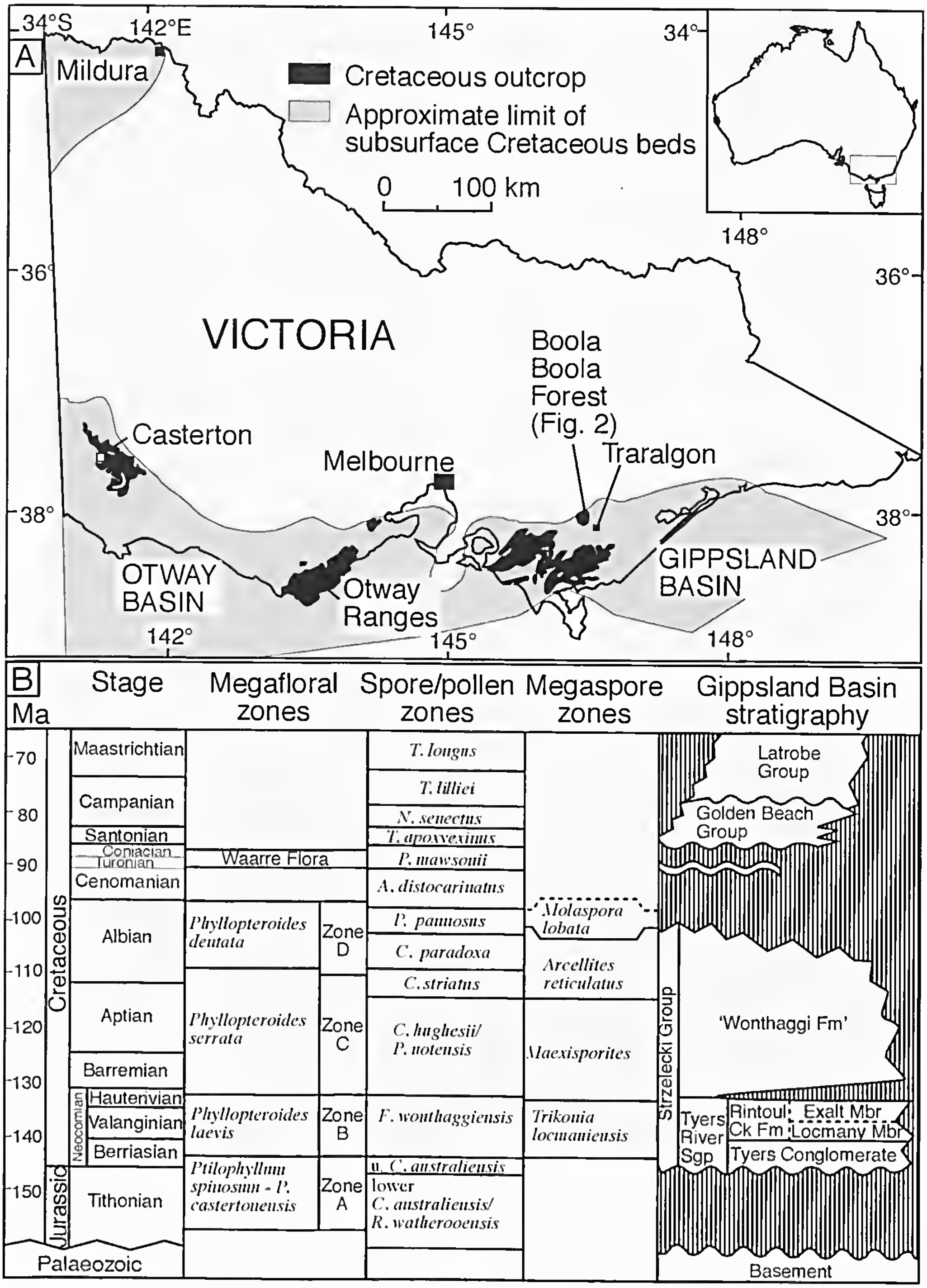

Fig 1. Geographic and stratigraphic position of the fossil beds. A. Map of Victoria showing the distribution of Cretaceous sedimentary rocks and the location of Boola Boola Forest; B. Cretaceous stratigraphy and biozones of the Gippsland Basin. Adapted from Douglas (1969), Cantrill & Webb (1987), Helby et al. (1987), Smith (1988), Tosolini et al. (1999) and Tosolini et al. (2002).

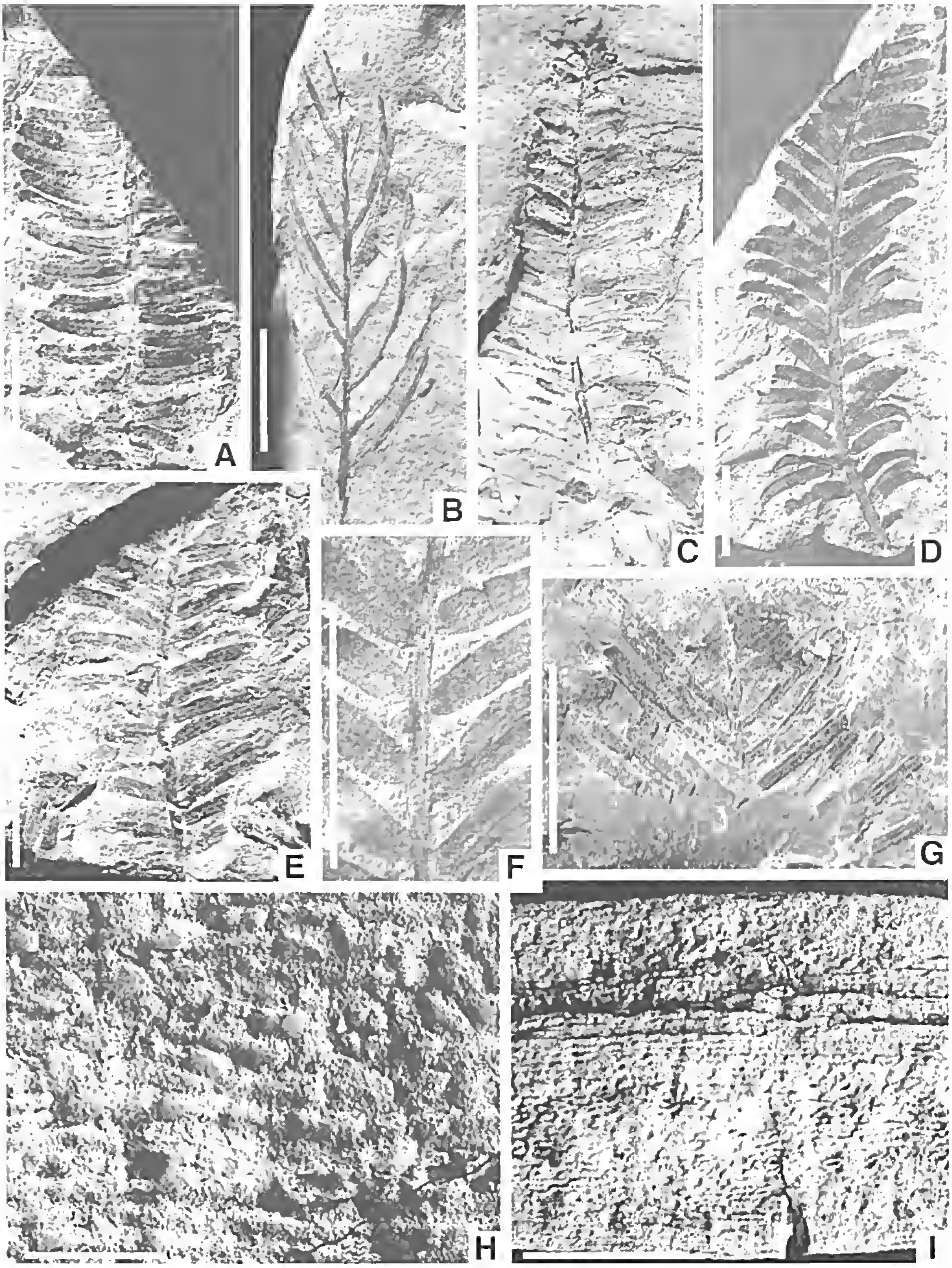

Fig 2. *Bellarinea richardsii*. A. Shoot displaying typical leaf arrangement, MVP209950B, Loc. RC20A; B. Shoot with incurved, narrow, falcate leaves, MVP209943, Loc. RC17D; C. Immature or under-developed shoot with leaves reducing in size towards the shoot apex, MVP209949, Loc. RC17D; D. Shoot displaying typical pseudodistichous leaf arrangement, MVP209942 (holotype), Loc. L14; E. shoot displaying typical leaf arrangement and form, NMVP209950A, Loc. RC20A; F. Enlargement of typical shoot axis showing pseudodistichous, spirally inserted, leaf bases, MVP209942, Loc. L14; G. Shoot with narrow coalified leaves, MVP209948, Loc. RC20A; H. Scanning electron micrograph of MVP209948 showing regular epidermal cells with bulging periclinal walls and stomates with papillae; I. Scanning electron micrograph of MVP209948 showing stomates in longitudinal bands either side of the midvein. Scale bar = 10 mm for A-G; 100 μm for H; 1 mm for I.

However, this pollen is likely to be associated with araucarian cone scales and small, slender twigs bearing appressed, scale-like leaves assigned to *Brachyphyllum tyersensis* Tosolini & Nagalingum (in McLoughlin et al. 2002). *Brachyphyllum tyersensis* has wax-filled, obliquely orientated, cyclocytic stomates with four to six subsidiary cells typical of araucariacean leaves. Cheirolepidiacean pollen is represented by *Corollina* sp. cf. *C. torosa* (Reisinger) Klaus. However, it is unlikely that *B. richardsii* is cheirolepidiaceous as the leaves of that family are typically scale-like with strongly sunken stomates protected by prominent papillae, and borne in spirals, whorls or opposite-decussate arrangement (Alvin 1982). Specimens attributed to *Otwayia hermata* Tosolini & McLoughlin (in McLoughlin et al. 2002) from the Boola Boola assemblage show these foliar features and are the likely affiliates of the *Corollina* pollen. Podocarpaceae is represented by pollen referable to *Podocarpidites* sp. cf. *P. ellipticus* Cookson and *Microcachyridites antarcticus* Cookson. Taxodiacean/cupressacean pollen is unknown from these deposits and has only been regularly reported in post-Cretaceous sediments in Australia (Macphail et al. 1994). Nevertheless, taxodiacean macrofossils are known from the mid-Cretaceous (Peters & Christophel 1978) suggesting that the early pollen record of this group has been overlooked on this continent. Small asulcate grains such as those referred to *Spheripollenites*, although not recorded from Boola Boola, are found elsewhere in the Victorian Early Cretaceous, and these are not unlike the pollen of extant Taxodiaceae. Florin (1963) argued that most *Elatocladus*-type shoots from the Southern Hemisphere, including *Bellarinea*, were probably podocarpaceous but the dearth of consistently distinctive architectural or cuticular characters separating Taxodiaceae and Podocarpaceae foliage and the absence of reproductive remains associated with the Boola Boola fossils prevents definitive familial assignment of *B. richardsii*.

Leaves of *B. richardsii* are basally twisted, which results in a distichous appearance (Fig. 2F). This leaf arrangement is common among some extant and fossil Taxodiaceae (e.g., *Metasequoia*, *Taxodium* and *Sequoia*) and Podocarpaceae (e.g., *Falcatifolium*, *Afrocarpus*, *Nageia*, *Retrophyllum*, *Prumnopitys*, *Dacrycarpus*, *Acmopyle*, *Mataia*, *Smithtonia*, and *Wilhungia*). Those extant Taxodiaceae with linear leaves in pseudodistichous arrangement are mostly deciduous and have thin cuticle with either a smooth surface (*Taxodium*: Alvin & Boulter 1974, Sung Soo Whang & Hill 1999) or with a uneven surface caused by lobing of the periclinal walls of epidermal cells (*Metasequoia*: Qin Leng et al. 2001). Some Taxodiaceae lack Florin rings (e.g., *Sequoia*, *Cunninghamia*) but others (e.g., *Metasequoia*, *Athrotaxus*) have Florin rings that are typically lobed (Oladele 1983). Stomata of linear-leafed Taxodiaceae, such as *Metasequoia*, generally have apertures orientated parallel to the leaf axis, strongly cutinized guard cells, and around 4–6 subsidiary cells that are not strongly differentiated from surrounding epidermal cells. The cuticle of *B. richardsii* is thin, and very difficult to prepare compared to co-fossilized Bennettitales and other conifers; this thin cuticle is further evidence for a deciduous habit. Its stomata are axially aligned and the subsidiary cells are, at best, only weakly raised. Some podocarp genera, such as *Falcatifolium* and *Retrophyllum*, produce short shoots with a pseudodistichous array of bifacial leaves whereas others, such as *Dacrycarpus* and *Acmopyle*, show similar twisting at the base of leaves but the leaves are bilaterally flattened. *Bellarinea richardsii*, with symmetrical bands of stomata restricted to the abaxial surface appears to possess bifacial leaves. Most Podocarpaceae have smooth cuticle but some possess low papillae, irregular ridges, or the epidermal cells have an inflated appearance or verrucate texture (Hill & Pole 1992). In many cases podocarps have prominent Florin rings around the stomates but in some cases (e.g., *Smithtonia* and *Wilhungia*) these may be poorly developed or divided into irregular lobes. All extant Podocarpaceae are evergreen, and most have a relatively robust cuticle. Possession of a distinct abaxial stomatal band on either side of the midvein, longitudinally aligned, slightly inflated epidermal cells, and weakly papillate subsidiary cells, is consistent with Florin's (1952) placement of *Bellarinea* in Podocarpaceae but an affinity to Taxodiaceae can not be excluded.

Comparisons with other mid- to late Mesozoic conifer fossils

Several conifer fossils with similar gross morphology to *B. richardsii* have been recorded from Australian Jurassic-Cretaceous strata (Table 1). These have been variously assigned to the form-genus *Elatocladus*, or to genera with implied cuticular or reproductive affinities to modern conifer families. All of these fossils differ to a greater or lesser degree to the specimens here assigned to *B. richardsii*.

Although Douglas (1969) did not describe any conifers from the Victorian Lower Cretaceous he listed '*Elatocladus* sp. a' in the Boola Boola fossil flora. These remains are probably conspecific with *B. richardsii* given the appearance of *Elatocladus* remains from this flora that he illustrated in later studies (Douglas 1994). Douglas (1969) also figured the apex of a conifer leaf assigned to '*Elatocladus* sp. b' from Boola Boola. However, this illustration does not have sufficient detail to assess its affinity with *E. richardsii*. As part of an investigation into the sedimentology of the Tyers River Subgroup, Philip (1958) listed the presence of *Elatocladus* sp. cf. *E. confertus* and *E. mccoyi*, but these identifications were not supported by illustrations or descriptions.

Stirling (1892, 1900) assigned *Elatocladus*-like shoots from Aptian of the Gippsland Basin to *Palissya australis* McCoy. These shoots exhibit rhythmic growth of the leaves along their length, but differ from *B. richardsii* by having either spirally arranged leaves (Stirling 1892, Parris et al. 1995) or pseudodistichous leaves borne on shoots with multiple branches (Stirling 1900). At least some of these leaves also differ from *B. richardsii* in having bilaterally flattened leaves (see Parris et al. 1995, fig. 8a). The *Palissya australis* specimens were later transferred to *E. confertus* by Arber (1917) and considered synonymous with New Zealand, Antarctic and Indian specimens (Arber 1917, Sahni 1928). Medwell (1954) assigned several Victorian specimens to *E. confertus* but they were not figured or described and the specimens cannot be located. Townrow (1967) later re-assigned Arber's specimens of *E. confertus* to *Mataia podocarpoides* Townrow because they exhibited irregular branching whereas the Antarctic type material has more or less pinnate branching. *Mataia podocarpoides* is further distinguished from *B. richardsii* by the possession of attached ovuliferous cones (Townrow 1967).

Elatocladus mccoyi was described by Florin (1952) based on an Aptian specimen from the Otway Basin. The leaves of both *B. richardsii* and *E. mccoyi* are borne spirally but twisted to give a distichous appearance. The lengths of some *B. richardsii* leaves fall within the size range of *E. mccoyi*, however, the two species are regarded as distinct because the leaves of the former are typically linear to oblong and straight to inflexed, whereas leaves of the latter are lanceolate to falcate and strongly reflexed. An additional Aptian specimen from the Otway Basin was assigned to *Elatocladus* sp. by Florin (1952) but this shoot has spirally arranged, 2.5–4.5 mm long, triangular leaves and should be transferred to *Pagiophyllum* or *Otwayia*.

Aptian twigs from the Gippsland and Otway basins assigned to *Bellarinea barklyi* have pseudodistichous leaves with decurrent bases (Florin 1952, Drinnan & Chambers 1986). This species has bifacial leaves 14–32 mm long and 1.8–3 mm wide. Most leaves of *B. richardsii* are slightly smaller than those of *B. barklyi*. The stomates of both *B. barklyi*, known only from the Aptian, and *B. richardsii*, recorded only from the Neocomian, are arranged in two longitudinal bands but the former is distinguished by having sinuous-walled epidermal cells in the non-stomatiferous areas.

Elatocladus planus (Feistmantel) Seward has been recorded from numerous Gondwanan Jurassic-Cretaceous localities (Townrow 1967). In Australia, *E. planus* has been described from the Talbragar flora of New South Wales (Walkom 1921), Algebuckina Sandstone, South Australia (Glaessner & Rao 1955) and several Mesozoic formations of Queensland (Walkom 1917, 1919). It is not clear that all, or any, of the Australian forms referred to this species are conspecific with the Indian type material. Townrow (1967) noted that this species 'almost certainly will prove to be composite' upon further investigation. This suggestion proved correct in the case of the ?Middle Jurassic Talbragar specimens, which were later reassigned to *Rissikia talbragarensis* White 1981. The Talbragar species differs from both *E. planus* and *B. richardsii* on the basis of its more closely spaced, longer leaves with distinct transverse striations (White 1981). Townrow (1967) excluded the South Australian specimens from his synonymy list for *E. planus*. McLoughlin (1996) suggested that the South Australian *E. planus* (Glaessner & Rao 1955) specimens may be synonymous with *Elatocladus ginginensis* McLoughlin but could not confirm their identity as the former are ill-preserved. *Bellarinea richardsii* is broadly similar in morphology and size to *Elatocladus ginginensis* from the Neocomian-Barremian of Western Australia (McLoughlin 1996). The latter has leaves with variably contracted or decurrent bases. Its leaves are distally tapered but lack a mucronate tip. In contrast, *B. richardsii* has leaves with a mucronate apex and decurrent bases that are not contracted. *Elatocladus*-like shoots originally described by Walkom (1918) from the Lower Cretaceous of Queensland have subsequently been assigned to a new species,

								
Characters	***B. richardsii***	***B. barklyi***	***E. planus***	***E. mccoyi***	***E. talbragarensis***	***E. ginginensis***	***E. baddowensis***	***M. podocarpoides***
Shoot length	84 mm	c. 100 mm	>90 mm	>25 mm	127 mm	51 mm	>41 mm	30 mm; shoots commonly retained in connection with parent shoots
Leaf arrangement	spiral; basally twisted to pseudodistichous	spiral; basally twisted to pseudodistichous	spiral; basally twisted to pseudodistichous	spiral; basally twisted to pseudodistichous	spiral; basally twisted to pseudodistichous	spiral; basally twisted to pseudodistichous	spiral; basally twisted to pseudodistichous; opposite-subopposite	spiral; basally twisted to be more or less distichous except near base of ultimate shoots where they remain spiral
Maximum leaf length	16 mm	32 mm	26 mm	11 mm	c. 60 mm	20 mm	17 mm	15 mm
Maximum leaf width	2 mm	3 mm	1.2 mm	1 mm	2 mm	1 mm	2.5 mm	4 mm
Leaf shape	linear; straight, inflexed or reflexed	linear to lanceolate	linear; commonly reflexed	linear; generally reflexed	linear; in some cases slightly reflexed or inflexed	linear; in some cases slightly reflexed or inflexed	oblong to lanceolate; straight or slightly inflexed	oblanceolate; commonly reflexed
Leaf orientation	40-90° from axis	40-90° from axis	60-90° from axis	50-75° from axis	20-90° from axis	35-60° from axis	45-80° from axis	40-80° from axis
Leaf cross-section	uncertain probably flat or slightly keeled	uncertain; probably keeled	uncertain; probably keeled	uncertain; probably keeled	uncertain; probably keeled	uncertain; probably keeled	uncertain; probably flattened	triangular; strongly keeled below midvein
Leaf base	twisted, broadly decurrent	slightly contracted, non-petiolate, twisted, strongly decurrent	not significantly contracted, strongly decurrent	slightly contracted, twisted, broadly decurrent	in most cases markedly decurrent (specimens with transverse striae on leaves here excluded)	slightly contracted, non-petiolate, twisted, slightly decurrent	slightly contracted, weakly decurrent	tapered; markedly decurrent
Leaf apex	obtuse, commonly mucronate	subacute to obtuse	acutely pointed to rounded	acute to almost obtuse	blunt obtuse or rounded	rounded or blunt obtuse	rounded or blunt obtuse	variable; rounded, acute, or slightly mucronate
Stomatal distribution	hypostomatic; 0.3 mm broad stomatiferous band in centre of lamina either side of midvein	hypostomatic; 0.5 mm broad stomatiferous band in centre of lamina either side of midvein	not available	not available	not available	not available	not available	hypostomatic or very unequally amphistomatic; stomata restricted to zones in uncertain position
Arrangement of stomates	arranged in at least two longitudinal files; apertures longitudinally orientated	haplocheilic stomates with mostly oblique apertures in weakly defined longitudinal rows	not available	not available	not available	not available	not available	monocyclic; arranged in longitudinal, though often irregular rows apertures mostly longitudinally orientated
Subsidiary cells	papillate	4-6; never shared; slightly papillate; slightly raised to form weak Florin ring	not available	not available	not available	not available	not available	4-6; never shared but sometimes adjacent; bearing hemispherical papillae; Florin ring absent
Guard cells	sunken	slightly sunken	not available	not available	not available	not available	not available	slightly sunken
Papillae	present, only on subsidiary cells	present only on subsidiary cells	not available	not available	not available	not available	not available	generally present only on subsidiary cells
Epidermal cells	rectangular	generally rectangular or with slightly sinuous anticlinal walls	not available	not available	not available	not available	not available	mostly rectangular with slightly sinuous anticlinal walls
Affiliated reproductive structures	no obvious associated fruits	no obvious associated fruits	no obvious associated fruits	no obvious associated fruits	associated with 120 mm long cones comprised of c. 30 spirals of cone scales each bearing a ?solitary seed	no obvious associated fruits	no obvious associated fruits	seed cone spike-like; 30 mm long; bearing 8-12 spirally arranged units comprising a bract and axillary ovuliferous scale bearing two stalked seeds
Type formation or locality	Rintoul Creek Formation, Gippsland Basin, Australia	lower Eumeralla Formation, Otway Basin, Australia	Vemavaram Formation Cauvery-Palar Trough, India	lower Eumeralla Formation, Otway Basin, Australia	Purlawaugh Formation, Surat Basin, Australia	Leederville Formation, Western Australia	Maryborough Formation, Maryborough Basin, Australia	Clent Hills, New Zealand
Age of type formation	Neocomian	Aptian	?Barremian-?Aptian	Aptian	?Bajocian-?Callovian	Neocomian-Barremian	Aptian	?Middle Jurassic

Table 1. Comparison of conifer fossils with similar gross morphology to *Bellarinea richardsii* from Mesozoic sediments of Australia, India and New Zealand. Information from Walkom (1921), Sahni (1928), Florin (1952), Townrow (1968), White (1981), McLoughlin (1996) and McLoughlin et al. (2000).

E. baddowensis (McLoughlin et al. 2000), that is distinguished by its oblong to lanceolate leaves with rounded apices and slightly contracted bases.

Species of *Elatocladus* described from the Yorkshire Jurassic (Harris 1979), although similar in general leaf morphology to *Bellarinea richardsii*, all represent indeterminate shoots and exhibit either branching or buds, both of which are absent from the Boola Boola specimens. Several species of *Elatocladus* described from the Jurassic and Early Cretaceous of Antarctica (Halle 1913, Gee 1989, Cantrill 2000a,b, Cantrill & Falcon-Lang 2001) differ from *B. richardsii* by being branched and indeterminate. Of these, *E. australis* has lateral shoot units subtended by a resting bud of scales, which Cantrill (2000a) suggested may be evidence of deciduousness or at least arrested growth. The latter is most likely given that Cantrill's figure 7.1 shows a shoot of rhythmic growth with large leaves either side of a region of restricted growth

Associated plant fossils.

Bellarinea richardsii is by far the most abundant of the three conifer foliage species in the Boola Boola macroflora, but this may reflect a deciduous habit rather than floristic dominance. The assemblage also contains several other gymnosperms including bennettitaleans (*Otozamites* spp.), pentoxylaleans (*Taeniopteris daintreei* McCoy), and pteridosperms of uncertain affinity (*Rintoulia variabilis*, *Pachydermophyllum austropapillosa* and *Komlopteris indica*; McLoughlin et al. 2002). Ferns are represented by around ten foliage-based species (Douglas 1973) and lycophytes are represented by abundant detached microphylls and 16 species of megaspores (McLoughlin et al. 2002). *Bellarinea richardsii* is most commonly associated with *Taeniopteris daintreei*, *Rintoulia variabilis* and *Otozamites* spp. in floodbasin siltstones and crevasse-splay sands (McLoughlin et al. 2002). Based on their abundance in these sediments, their taphonomy, associated fossils, and previous palaeoecological interpretations of this plant group (Douglas & Williams 1982), *Bellarinea richardsii* is interpreted to have constituted an upper storey tree. It occupied relatively moist floodbasin environments in alluvial valley systems during the initial establishment of the Gippsland Basin rift.

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REFERENCES

ALVIN, K. L., 1982. Cheirolepidiaceae: Biology, structure and palaeoecology. *Review of Palaeobotany and Palynology* 37: 71–98.

ALVIN, K. L. & BOULTER, M. C., 1974. A controlled method of comparative study for taxodiaceous leaf cuticles. *Botanical Journal of the Linnean Society* 69: 277–286.

ANDERSON, J. M. & ANDERSON, H. M., 1985. *Palaeoflora of southern Africa. Prodromus of South African megafloras Devonian to Lower Cretaceous*. A.A. Balkema, Rotterdam, 416 pp.

ARBER, E. A. N., 1917. The earlier Mesozoic floras of New Zealand. *New Zealand Geological Survey Palaeontological Bulletin* 6: 1–80.

CANTRILL, D. J., 1991. Broad leafed coniferous foliage from the Lower Cretaceous Otway Group, south eastern Australia. *Alcheringa* 15: 177–190.

CANTRILL, D. J., 1992. Araucarian foliage from the Lower Cretaceous of southern Victoria, Australia. *International Journal of Plant Science* 153: 622–645.

CANTRILL, D. J., 2000a. A Cretaceous (Aptian) flora from President Head. Snow Island, Antarctica. *Palaeontographica Abt.B* 253: 153–191.

CANTRILL, D. J., 2000b. A new macroflora from the South Orkney Islands, Antarctica: evidence of an Early to Middle Jurassic age for the Powell Island Conglomerate. *Antarctic Science* 12: 185–195.

CANTRILL, D. J. & DOUGLAS, J. G., 1988. Mycorrhizal conifer roots from the Lower Cretaceous of the Otway Basin, Victoria. *Australian Journal of Botany* 36: 257–272.

CANTRILL, D. J. & FALCON-LANG, H. A., 2001. Cretaceous (Late Albian) coniferales of Alexander Island, Antarctica. 2. Leaves, reproductive structures and roots. *Review of Palaeobotany and Palynology* 115: 119–145.

CANTRILL, D. J. & WEBB, J. A., 1987. A reappraisal of *Phyllopteroides* Medwell (Osmundaceae) and its stratigraphic significance in the Lower Cretaceous of eastern Australia. *Alcheringa* 11: 59–85.

CONSTANTINE, A. E. & HOLDGATE, G. R., 1993. *Selwyn Symposium, Gippsland Basin Excursion Guide*, 20 pp. Geological Survey of Victoria (unpublished).

DETTMANN, M. E., 1963. Upper Mesozoic microfloras from south-eastern Australia. *Proceedings of the Royal Society of Victoria* 77: 1–148.

DOUGLAS, J. G., 1969. The Mesozoic floras of Victoria, Parts 1 and 2. *Geological Survey of Victoria Memoir* 28: 1–310.

DOUGLAS, J. G., 1973. The Mesozoic floras of Victoria, Part 3. *Geological Survey of Victoria Memoir* 29: 1–185.

DOUGLAS, J. G., 1988. Gippsland Basin. In *Geology of Victoria*, J.G. Douglas & J.A. Ferguson, eds, Geological Society of Australia, Melbourne, 228–233.

DOUGLAS, J. G., 1994. Cretaceous vegetation: the macrofossil record. In R.S. Hill, ed., *History of the Australian Vegetation: Cretaceous to Recent*. Cambridge University Press, Cambridge, 171–188.

DOUGLAS, J. G. & WILLIAMS, G. E., 1982. Southern polar forests: the Early Cretaceous floras of Victoria and their palaeoclimatic significance. *Palaeogeography, Palaeoclimatology, Palaeoecology* 40: 199–212.

DRINNAN, A. N. & CHAMBERS T. C., 1986. Flora of the Lower Cretaceous Koonwarra fossil bed (Korumburra Group), South Gippsland, Victoria. *Memoirs of the Association of Australasian Palaeontologists* 3: 1–77.

FLORIN, R. R., 1952. On two conifers from the Jurassic of south-eastern Australia. *The Palaeobotanist* 1: 177–182.

FLORIN, R. R., 1963. The distribution of conifer and taxad genera in time and space. *Acta Horti Bergiani* 20: 121–312.

GEE, C. T., 1989. Revision of the Late Jurassic/Early Cretaceous flora from Hope Bay, Antarctica. *Palaeontographica Abt.* B 213: 149–214.

GLAESSNER, M. F. & RAO, V. R., 1955. Lower Cretaceous plant remains from the vicinity of Mount Babbage, South Australia. *Transactions of the Royal Society of South Australia* 78: 134–140.

HALLE, T. G., 1913. The Mesozoic flora of Graham Land, *Wissenschaftliche Ergebnisse der Schwedischen Südpolar-expedition 1901–1903* 3: 1–123.

HARRIS, T. M., 1979. *The Yorkshire Jurassic Flora. V. Coniferales*. British Museum of Natural History, London, 166 pp.

HELBY, R., MORGAN, R. & PARTRIDGE, A. D., 1987. A palynological zonation of the Australian Mesozoic. *Memoirs of the Association of Australasian Palaeontologists* 4: 1–94.

HILL, R. S. & POLE, M., 1992. Leaf and shoot morphology of extant *Afrocarpus, Nageia* and *Retrophyllum* (Podocarpaceae) species, and species with similar leaf arrangement, from Tertiary sediments in *Australasia. Australian Systematic Botany* 5: 337–358.

MACPHAIL, M. K. ALLEY, N., TRUSWELL, E. M., & SLUITER, I. R. K., 1994. Early Tertiary vegetation: Evidence from spores and pollen. In *History of the Australian Vegetation: Cretaceous to Recent*, R. S. Hill., ed., Cambridge University Press: Cambridge, 189–262.

MCCOY, F., 1860. A commentary on "A communication made by the Rev. W.B. Clarke to His Excellency Sir Henry Barkly, K.C.B &c., &c. President of the Royal Society of Victoria, on Professor McCoy's new *Taeniopteris, &c., &c. Transactions of the Royal Society of Victoria* 5: 96–107.

MCCOY, F., 1874. *Prodromus of the Palaeontology of Victoria, Decade 1*. John Ferres, Government Printer, Melbourne, 43 pp.

MCCOY, F., 1875. *Prodromus of the Palaeontology of Victoria, Decade 2*. George Skinner, Acting Government Printer, Melbourne, 37 pp.

MCLOUGHLIN, S., 1996. Early Cretaceous macrofloras of Western Australia. *Records of the Western Australian Museum* 18: 19–65.

MCLOUGHLIN, S., TOSOLINI, A-M. P., & DRINNAN, A. N., 2000. Revision of an Early Cretaceous macroflora from the Maryborough Formation, Maryborough Basin, Queensland, Australia. *Memoirs of the Queensland Museum* 45: 483–503.

MCLOUGHLIN, S., TOSOLINI, A-M. P., NAGALINGUM, N. S. & DRINNAN, A. N., 2002. The Early Cretaceous (Neocomian) flora and fauna of the lower Strzelecki Group, Gippsland Basin, Victoria, Australia. *Memoirs of the Association of Australasian Palaeontologists*, 26: 1–144.

MEDWELL, L. M., 1954. A review and revision of the flora of the Victorian Lower Jurassic. *Proceedings of the Royal Society of Victoria* 65: 63–111.

OLADELE, F. A., 1983. Scanning electron microscope study of stomatal complex configuration in Cupressaceae. *Canadian Journal of Botany* 61: 1232–1240.

PARRIS, K. M., DRINNAN, A. N. & CANTRILL, D. J., 1995. *Palissya* cones from the Mesozoic of Australia and New Zealand. *Alcheringa* 19: 87–111.

PETERS, M. D. & CHRISTOPHEL, D. C. 1978. *Austrosequoia wintonensis*, a new taxodiaceous cone from Queensland, Australia. *Canadian Journal of Botany* 56: 3119–3128.

PHILIP, G. M., 1958. The Jurassic sediments of the Tyers Group, Gippsland, Victoria. *Proceedings of the Royal Society of Victoria* 70: 181–199.

POLE, M. S, 1995. Late Cretaceous macrofloras of Eastern Otago, New Zealand: gymnosperms. *Australian Systematic Botany* 8: 1067–1106.

POLE, M. S., 2000. Mid-Cretaceous conifers from the Eromanga Basin, Australia. *Australian Systematic Botany* 13: 153–197.

QIN LENG, HONG YANG, QUN YANG & JIANPING ZHOU, 2001. Variation of cuticle micromorphology of *Metasequoia glyptostroboides* (Taxodiaceae). *Botanical Journal of the Linnean Society* 136: 207–219.

RICH, P. V., RICH T. H., WAGSTAFF, B. E., MCEWEN MASON, J., DOUTHITT, C. B., GREGORY, R. T. & FELTON, E. A. 1988. Evidence for low temperatures and biologic diversity in Cretaceous high latitudes of Australia. *Science* 242: 1403–1406.

SAHNI, B., 1928. Revision of Indian fossil plants. Pt. 1. Coniferales (a. Impressions and incrustations). *Geological Survey of India, Palaeontographica Indica, Memoir, N.S.* 11: 1–49.

SEWARD, A. C., 1904. On a collection of Jurassic plants from Victoria. *Records of the Geological Survey of Victoria* 1: 155–211.

SMITH, G. C., 1988. Oil and gas. In *Geology of Victoria*, J.G. Douglas & J.A. Ferguson, eds, Geological Society of Australia, Melbourne, 514–546.

STIRLING, J., 1892. Notes on the fossil florula and faunae of the Gippsland carbonaceous area. *Victorian Department of Mines, Special Report Coalfields* 1: 10–13.

STIRLING, J., 1900. Notes on the fossil flora of South Gippsland. *Victorian Department of Mines, Special Report Coalfields* 7: 1–6.

SUNG SOO WHANG & HILL, R. S., 1999. Late Palaeocene Cupressaceae macrofossils at Lake Bungarby, New South Wales. *Australian Systematic Botany* 12: 241–254.

TOSOLINI, A-M. P., MCLOUGHLIN, S. & DRINNAN, A. N., 1999. Stratigraphy and sedimentary facies of the Neocomian-Barremian lower Strzelecki Group, Gippsland Basin, Victoria. *Australian Journal of Earth Sciences* 46: 951–970.

TOSOLINI, A-M. P., MCLOUGHLIN, S. & DRINNAN, A. N., 2002. Early Cretaceous megaspore assemblages from southeastern Australia. *Cretaceous Research* 23: 807–844.

TOWNROW, J. A., 1967. On *Rissikia* and *Mataia* podocarpaceous conifers from the lower Mesozoic of southern lands. *Papers and Proceedings of the Royal Society of Tasmania* 101: 103–136.

WALKOM, A. B., 1917. Mesozoic floras of Queensland. Part 1.-continued. The flora of the Ipswich and Walloon Series. (d.) Ginkgoales, (e.) Cycadophyta, (f.) Coniferales. *Geological Survey of Queensland Publication* 259: 1–49.

WALKOM, A. B., 1918. Mesozoic floras of Queensland. Part 2. The flora of the Maryborough (Marine) Series. *Geological Survey of Queensland Publication* 262: 1–21.

WALKOM, A. B., 1919. Mesozoic floras of Queensland. Parts 3 and 4. The floras of the Burrum and Styx River Series. *Geological Survey of Queensland Publication* 263: 1–77.

WALKOM, A. B., 1921. Mesozoic floras of New South Wales. Part 1 — Fossil plants from the Cockabutta Mountain and Talbragar. *Memoirs of the Geological Survey of New South Wales, Palaeontology* 12: 1–21.

WHITE, M. E., 1981. Revision of the Talbragar Fish Bed Flora (Jurassic) of New South Wales. *Records of the Australian Museum* 33: 695–721.

WHITE, M. E., 1986. *The Greening of Gondwana*. Reed Books, Frenchs Forrest, N.S.W. 256 pp.

LINGULIDA (BRACHIOPODA) FROM THE EARLY PERMIAN OF ARGENTINA

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A small fauna of inarticulate brachiopods from the lower beds of the Santa Elena Formation of the Calingasta-Uspallata Basin, Mendoza Province, Argentina is documented. The new genus *Argentiella*, type species *Argentiella stappenbecki* sp. nov., is described. *Orbiculoidea* sp. is also documented from the same fauna. The fauna occurs in beds which indicate an initial transgressive event overlying fresh water, plant bearing strata.

Keywords: Lingulida, Brachiopoda, Early Permian, Argentina

REPRESENTATIVES of the Lingulida (usually referred to as inarticulate brachiopods) have been widely recorded from the Late Palaeozoic of Argentina as summarised in the two volumes edited by Archangelsky (1987, 1996). Most of the records of inarticulate brachiopods are from localities and stratigraphical formations that are now regarded as being of Early Permian (Asselian–Sakmarian) age. Previous records have referred these brachiopods to the genera *Orbiculoidea* and *Lingula*. We note that several species of *Orbiculoidea* have been described and illustrated from the Early Permian of Argentina by authors such as Reed (1927), Fossa Mancini (1933), Feruglio (1934), Antelo (1972), and Lech (1990). However, so-called *Lingula* reports from Argentina have never been accompanied by illustrations. Study of new specimens has revealed that they are not true *Lingula*. While being allied to genera such as the Permian *Semilingula* (Popov 1990, in Egorov & Popov 1990), Carboniferous to Cretaceous *Lingularia* (Biernat & Emig 1993), Devonian to Carboniferous *Barroisella* (Hall & Clarke 1892) and the Brazilian Permian *Langella* (Mendes 1961), the Argentinian specimens demonstrate different dorsal internal visceral and muscular structures and hence appear to belong to a new genus.

In this paper we describe and figure the lingulid as *Argentiella* gen. nov., with the type species *Argentiella stappenbecki* sp. nov. We also figure a poorly known species of *Orbiculoidea*. Both come from the Permian strata of the Santa Elena Formation (Yrigoyen 1967) in the Calingasta-Uspallata Basin, Mendoza Province, Argentina.

Repository. The fossils described in this paper are registered with the prefix IPI (*Instituto de Paleontología, sección Invertebrados*), housed in the collections of the Miguel Lillo Foundation (San Miguel de Tucumán, Argentína).

STRATIGRAPHICAL, BIOSTRATIGRAPHICAL AND PALAEOECOLOGICAL IMPLICATIONS

Santa Elena Formation (Yrigoyen 1967) outcrops are located in the south-western extreme of the Argentine Precordillera, on the west flank of the Uspallata Hill, about 9 km east of Uspallata village in Mendoza province. (Fig 1A-D).

Material described herein has been collected from outcrops of the Santa Elena Formation south of the Uspallata Creek (Fig. 2), which would correspond to the "Tramojo Serie" defined by Keidel (1939). This stratigraphical section was considered Late Carboniferous by different authors (Dessanti & Rossi 1950; Rodriguez 1966). Rodriguez (1966), mentioned the presence of *Neospirifer leoncitensis* (Harrington 1938), *Dielasma* cf. *itaitubense* Derby

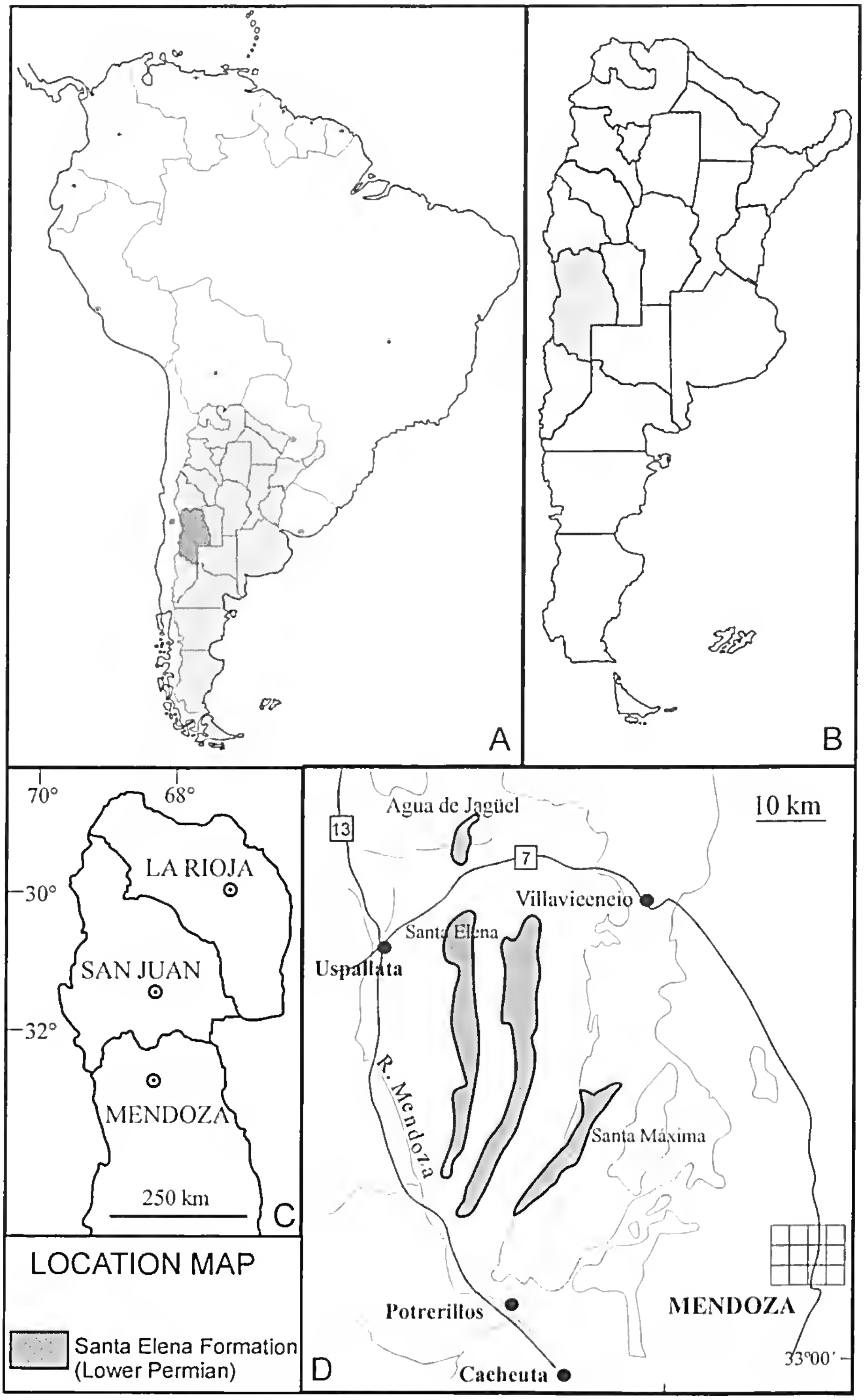


Fig. 1 A-D. Location of the study area.

1874, *Septosyringothyris keideli* (Harrington 1938), *Orbiculoidea* sp., *Pleurotomaria* sp. ind., *Conularia* sp., *Carbonicola promissa* (Frenguelli 1945), *Carbonicola* cf. *timenda* Leanza 1948, *Anthracomya diluta* Leanza 1948, *Naiadites*? sp. and gastropods. Later, Archangelsky & Lech (1985), suggested a youngest early Permian age for this formation. These authors identified eight fossiliferous horizons along this section, in which they identified brachiopods (*Lingula* sp., *Orbiculoidea annae* Feruglio 1934, *Orbiculoidea* aff. *saltensis* Reed 1927, *Orbiculoidea* sp., *Crurithyris* aff. *roxoi* (de Oliveira 1936), *Cancrinella* aff. *farleyensis* (Etheridge & Dun 1909) *Septosyringothyris*? sp., *Chonetes*? sp.), bivalves (*Aviculopecten* sp., *Cypricardinia*? sp., *Myonia* sp., *Promytilus* sp.) and gastropods. However, none of these species were described or figured by Archangelsky & Lech (1985).

Outcrops of the Santa Elena Formation south of the Uspallata Creek (Fig. 2), are distinguished by a sedimentary sequence characterized by a repetitive alternation of sandstone and mudstone facies. Fossils appear in the lower, middle and upper parts of the section (Fig. 3).

The Santa Elena section is interpreted as a shelf sequence, represented by stacking of successive upward coarsening parasequences that range from offshore-transitional (lingulid horizon) to a shoreface (S0 to S1 horizons). From the middle to the upper part of the section (S2 and S3 horizons), hummocky and swaley storm deposits, alternating with heterolithic facies, are recognised.

The brachiopod assemblage described herein appears in the lower part of this unit and is composed of inarticulate brachiopods (*Argentinella stappenbecki* sp. nov. and rare *Orbiculoidea* sp. A). The lingulid *Argentinella* is the dominant element in this assemblage, hence we informally named it the "Lingulida horizon" (S0), (Fig. 3). The "Lingulida horizon" is at the base of a stratigraphical interval about 10 m thick and is composed of alternating sandstones and black mudstones with calcareous concretions. This interval includes four fossil assemblages composed of brachiopods, bivalves and gastropods (Fig. 3): S0a, contains the brachiopods Trigonotretinae ind. and *Orbiculoidea* ind.; S0b, contains the brachiopods *Septosyringthyris* sp. and Trigonotretinae ind. and the bivalve *Schizodus*? sp.; S1 contains bivalves and S1' contains the brachiopod Trigonotretinae ind. and the bivalve Parallelodontidae ind. This fossiliferous interval (S0–S1', Fig. 3), is located immediately above a bed with a floral assemblage, approximately equivalent to the NBG (*Nothorhacopteris-Botrychiopsis-Ginkgophyllum*) Biozone (Archangelsky & Azcuy 1985).

In the middle part of the Santa Elena Formation a second fossiliferous assemblage has been identified (S2, Fig. 3). It is composed of brachiopods (*Costatumulus amosi* Taboada 1998, *Orbiculoidea* sp. B, *Crurithyris* sp. and *Septosyringothyris* sp.), bivalves and gastropods. Biostratigraphically, this fauna has been recently included in the *Costatumulus amosi* Biozone, considered to be Early Permian (Asselian), by Taboada (1998).

The "Lingulida horizon" represents an initial flooding event at the base of this sequence, the onset of marine conditions; it has been interpreted as a shallow marine environment by some authors (Archangelsky & Archangelsky 1987).

Brachiopods from the "Lingulida horizon" occur in "nests" or "patches" about 1 cm thick, concordant with the bedding. The valves occur in horizontal positions, with good shell preservation and a low proportion of fragmentary valves. A range of ontogenetic stages are preserved. Many of the valves are disarticulated. These characteristics suggest that the brachiopods from the "Lingulida horizon" can be considered a para-autochthonous assemblage. We assume that the lingulid occurrence indicates shallow water, transgressive conditions, with variations in salinity. Emig (1997) stressed the fragile nature of lingulid shells and their poor preservation in normal marine environments. As noted by Kowalewski (1996), lingulids in the Palaeozoic are often complete and well preserved and are common in assemblages with some reworking. Emig (1986) suggested that assemblages of flat-lying disarticulated valves may be produced by lower salinity, coarser grained sedimentation and storm events. Buatois et al. (2001) identified unusual communities characteristic of hyposaline environments in the Santa Elena Formation. Brackish ecosystems have also been identified from elsewhere in the Late Palaeozoic of Western Argentina and may suggest dilution of normal salinity related to melting of ice in southern Brazil.

SYSTEMATIC PALAEONTOLOGY

Subphylum LINGULIFORMEA Williams et. al. 1996

Family LINGULIDAE Menke 1828

Subfamily LINGULINAE Menke 1828

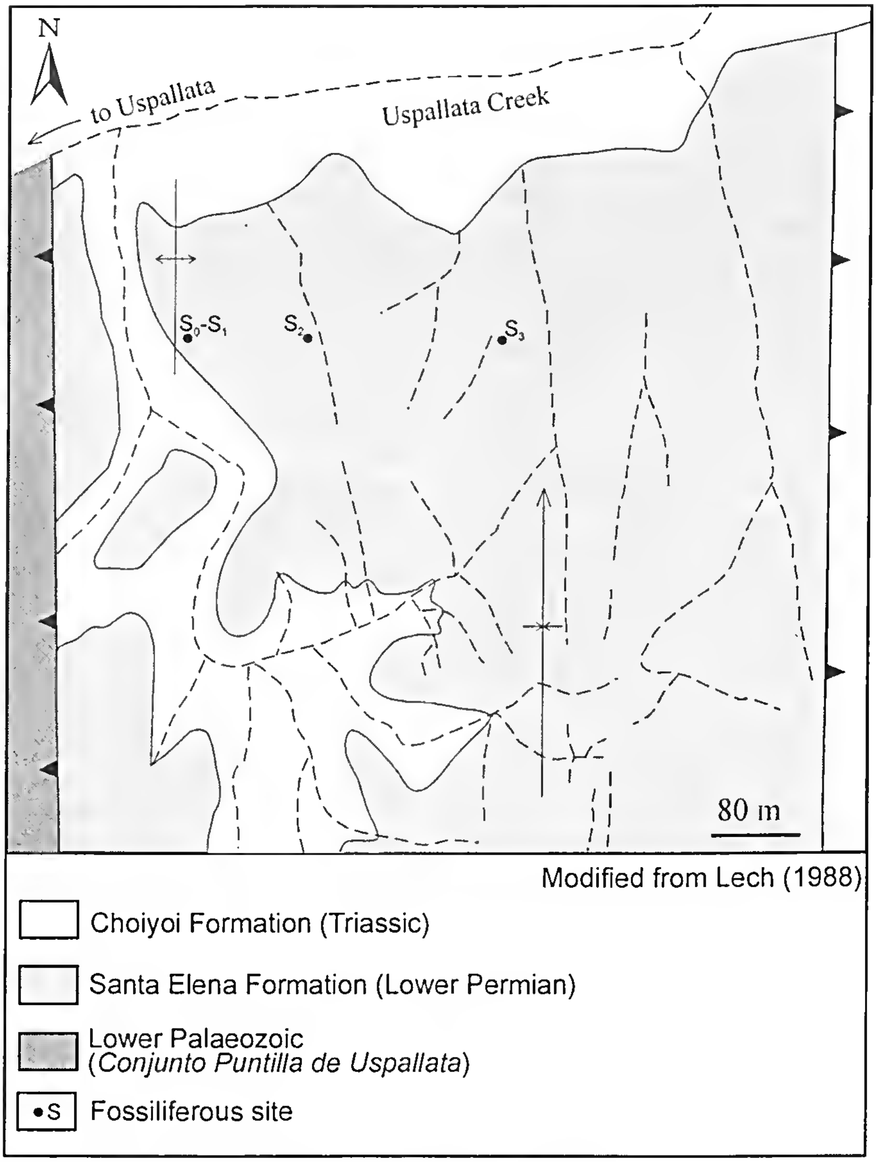


Fig. 2. Distribution of the Santa Elena Formation and the fossiliferous localities.

Genus **Argentiella** gen. nov.

Type species. *Argentiella stappenbecki* sp. nov.

Diagnosis. Feebly developed dorsal median ridge and ventral visceral area; both extend anteriorly about two-thirds of shell length. Anterior dorsal intercalated ridge absent. Ventral sub parallel-sided broad median ridge not developed in posterior fifth of shell.

Discussion. The new genus shares numerous features with other representatives of the Lingulidae Menke (1828) as defined by Holmer & Popov (2000). Emig (2003) has proposed further restrictions on the use of the family name, with which we agree. He has restricted the name to include only three genera (*Lingularia* Biernat & Emig 1993, *Lingula* Bruguiere 1797 and *Glottidia* Dall 1870), with other genera only provisionally placed in the family. We also note that the use of the generic *Lingula* is too broadly applied to

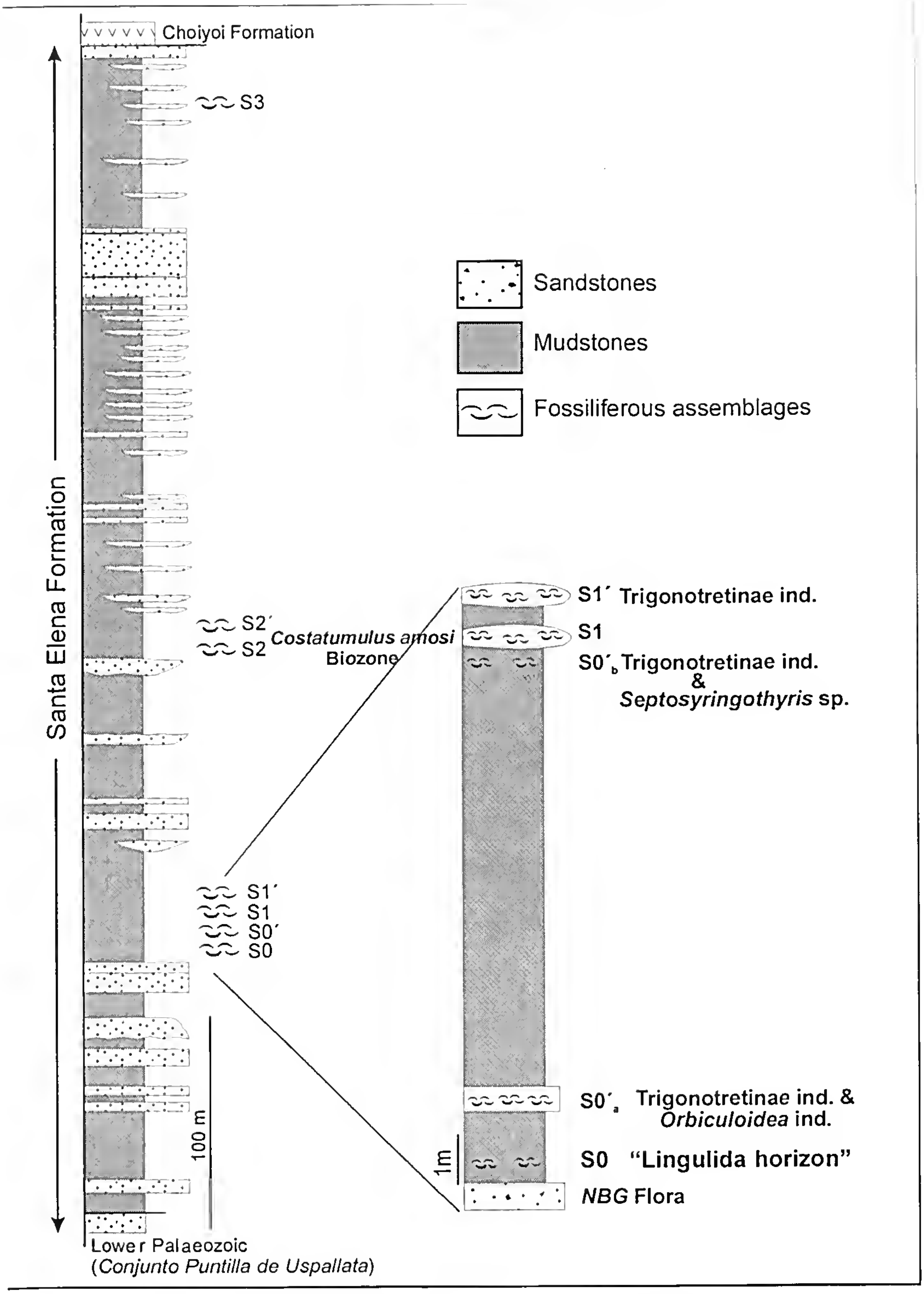
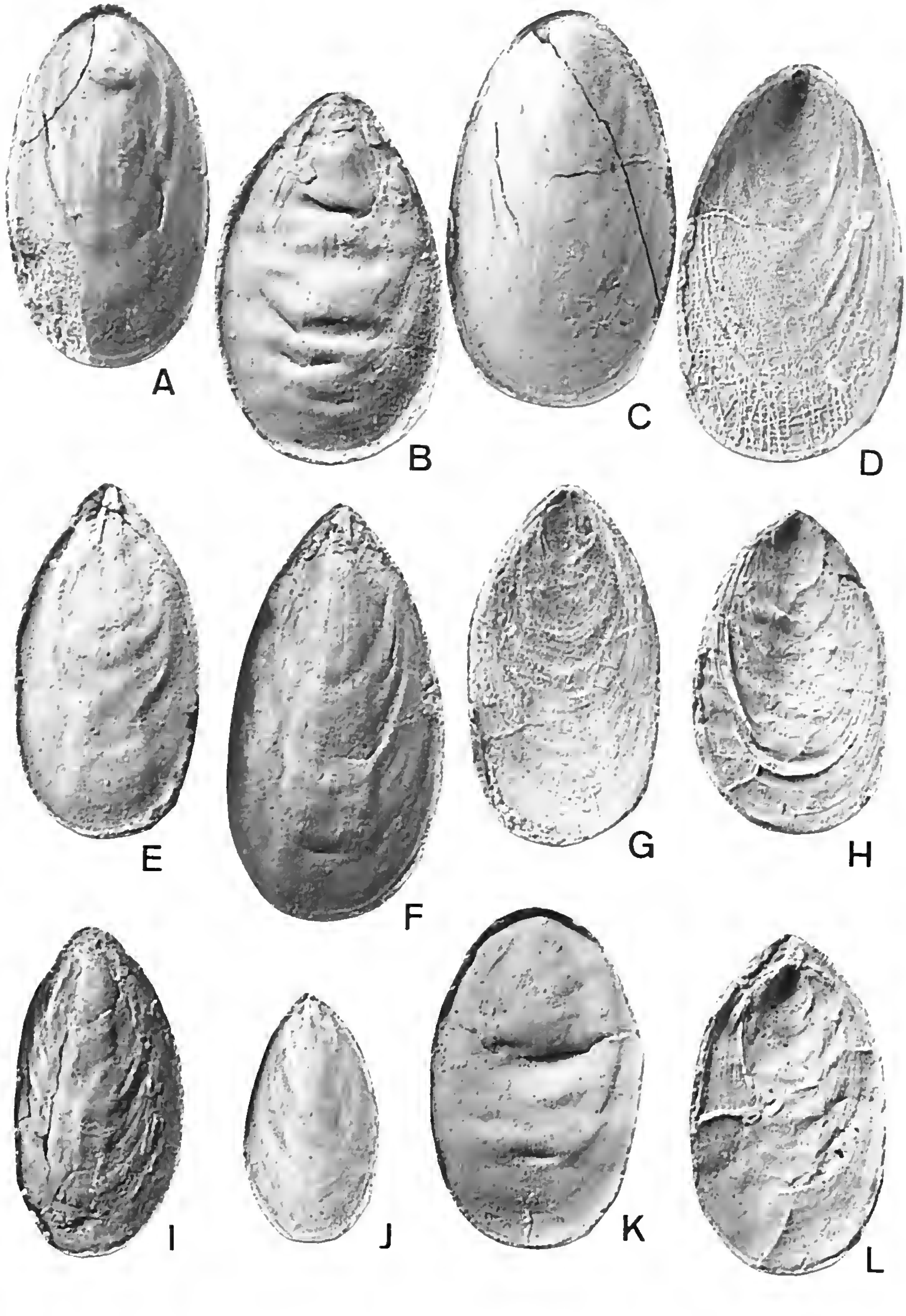


Fig. 3. Vertical distribution of fossiliferous assemblages in the studied section and detail of the lingulid horizon.


A
B
C
D
E
F
G
H
I
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L

Fig. 4 A-L, *Argentiella stappenbecki* sp. nov. A, IPI 3625, internal mould of dorsal valve, x6.5. B, IPI 3626, internal mould of ventral valve, x6. C,D, Holotype, IPI 3627a-b, internal and external moulds of dorsal valve, x7. E, IPI 3628a, internal mould of ventral valve, x6. F, IPI 3629, internal mould of ventral valve, x6.5. G, IPI 3628b, external mould of ventral valve, x6.5. H, IPI 3630, external mould of ventral valve, x5.5. I, IPI 3631, internal mould of ventral valve, x6.5. J, IPI 3632, internal mould of ventral valve, x6. K, IPI 3633, internal mould of dorsal valve, x6. L, IPI 3634, external mould of ventral valve, x6.

any generally linguliform fossil shell, as for example by Rodland & Bottjer (2001).

The new genus is closest to the Late Devonian-Early Carboniferous genus *Barroisella* Hall & Clarke (1892), type species *Barroisella campbelli* Cooper (1942), but lacks the dorsal anterior intercalated ridge of that genus. The ventral median ridge of the new genus does not extend as far posteriorly as in *Barroisella*.

Argentiella is also close to *Langella* Mendes (1961), a genus from similar age strata from eastern South America. *Langella*, with type species *Lingula imbituvensis* de Oliveira (1930) is well understood through the works of Martins (1948), Pinto (1949), Lange (1952), Mendes (1961) and Rocha-Campos (1967) who have illustrated many specimens of the type species. From *Langella*, the new genus is chiefly differentiated by means of its differing details of the dorsal and ventral median ridges and its low ventral fold (fastigium).

The Carboniferous to Cretaceous *Lingularia* Biernat & Emig (1993), type species *Lingularia similis* Biernat & Emig (1993), posses a different shell outline and distinctive internal visceral impressions, unlike those of *Argentiella*.

Semilingula Popov (1990, in Egorov & Popov 1990), with type species *Lingula? miloradovichi* Ifanova 1972, from the Permian of the Arctic and Australia, is also close morphologically to *Argentiella* but has a more parallel-sided shell and differing median internal ridge details to those of the new genus.

We consider that Ifanova (1972: 77–78) was correct in renaming *Lingula arctica* sp. nov. of Miloradovich (1936) as *Lingula? miloradovichi*, summarised by Archbold (1981: 174–175). *Lingula arctica* was first proposed by Wittenberg (1910) for a Triassic species and hence Miloradovich's (1936) proposal in the same generic name for a new taxon is an example of a primary homonym (ICZN Article 57). There was no indication by either Popov (1990) or Holmer & Popov (2000) that Miloradovich's usage was chosen under the provisions of ICZN Article 69.2.4. Neither work referred to Wittenberg's (1910) first usage of the binomen *Lingula arctica* or to Miloradovich' (1936) subsequent invalid usage of the binomen.

Argentiella stappenbecki sp. nov.
Figure 4A-L.

Holotype. IPI 3627a-b, a dorsal valve internal mould and external mould, figured as Figures 4A and 4B herein.

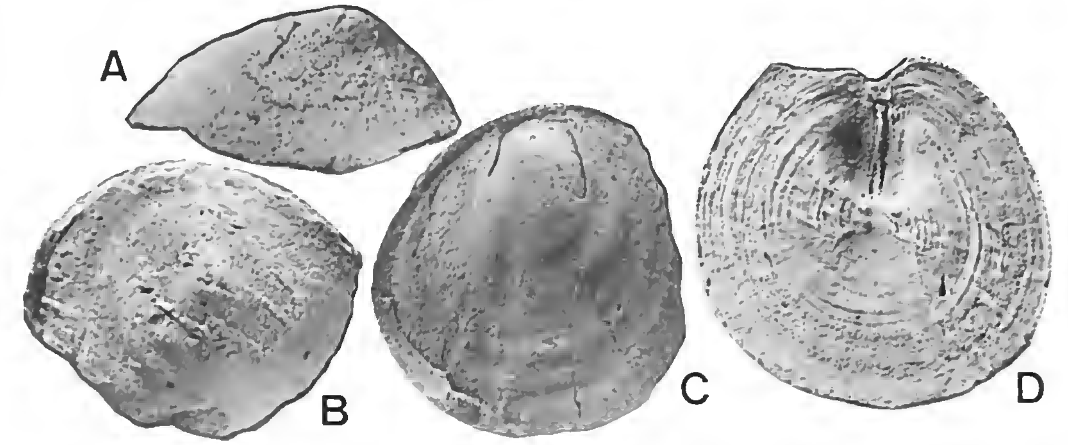

Fig. 5, A-D, *Orbiculoidea* sp. A,B, IPI 3635, internal mould of dorsal valve, x7.5. C, IPI 3636, internal mould of dorsal valve, x7. D, IPI 3637, external mould of ventral valve, x7.

Size Ranges. Maximum width – 1.9–5.8 mm; Maximum length – 3.1–9.4 mm.

Etymology. Named for Dr Richard Stappenbeck, pioneer Argentinian geologist.

Diagnosis. Shell elongate, oval; ventral umbo pointed; pedicle groove narrow. Propareas small distinct. Dorsal median ridge weakly impressed, extending anteriorly for two-thirds of valve length. Ventral visceral area extending about two-thirds valve length.

Material. Seven internal moulds of dorsal valves (IPI 3625, 3627a, 3633, 3638a, 3639, 3665, 3670); nine internal moulds of ventral valves (IPI 3626, 3628a, 3629, 3631, 3632, 3675, 3667a, 3669, 3671); five external moulds of dorsal valves (IPI 3627b, 3638b, 3666, 3668, 3672); four external moulds of ventral valves (IPI 3628b, 3630, 3634, 3667b).

Description. Shell elongate, oval in outline, biconvex. Maximum width at or anterior of mid-length. Shell exterior with fine growth lines and variably developed coarser growth stages. at times with appearance of 'rugae' (perhaps the result of slight compaction). Ventral valve with developed median fold (fastigium). Fold arises close to umbo and widens anteriorly at angle of 15° to 20°. Ventral umbo pointed and extended posteriorly. Pedicle groove narrow; propareas small, distinct. Ventral visceral area weakly impressed, vaguely flabellate. Twin, centrally located, ventral myophragms extend anteriorly up to two-thirds valve-length.

Dorsal valve evenly convex in cross-section. Dorsal median ridge weakly developed, extends anteriorly up to two thirds of valve length — weakly demarcated anteriorly from remainder of valve interior.

Discussion. Aspects of the morphology of *Argentiella stappenbecki* are close to those of the genera Barroisella and *Langella* and are discussed under the generic description.

Superfamily DISCINOIDEA Gray, 1840
Family DISCINIDAE Gray, 1840
Genus **Orbiculoidea** d'Orbigny, 1847

Orbiculoidea sp.
Figure 5 A-D

Material. Two internal moulds of dorsal valves (IPI 3635, 3636); one external mould of a ventral valve (IPI 3637).

Comments. Associated with the suite of *Argentiella* specimens are three specimens of a small species of *Orbiculoidea*: two dorsal valve internal moulds and one ventral valve internal mould. The dorsal valves are strongly convex, the ventral valve is essentially planar with a slightly convex apex. The pedicle track is narrow with a posterior foramen; the internal tube is narrow and opens in front of the posterior margin. The material, although limited, conforms well to the diagnosis of *Orbiculoidea* (type species *Orbicula forbesii* Davidson 1848) provided by Holmer & Popov (2000).

Orbiculoidea has been reported and illustrated from the Early Permian of Argentina by numerous authors (viz: Reed 1927: 132, pl. 13, fig. 1; Feruglio 1934 — based on illustrations provided by Fossa Mancini 1933: figs 1, 2; Antelo 1972: 162, pl. 1, fig. 5 and pl. 2, fig. 6; Amos 1979: 2 figs and Lech 1990: specimens referred to *Orbiculoidea* and *Oehlertella* including *Orbiculoidea asperotriangularis* Lech 1990, pl. 2, fig. 9 which is a *nomen nudum*). Available species names are *O. saltensis* Reed 1927 and *O. annae* Feruglio 1934, but these species require modern study based on large collections so that variability within the species can be defined.

Orbiculoidea is also abundant in the Early Permian of Brasil (de Oliveira 1930: 18, unnumbered plate and figure; Reed 1935: 201, 2 figs; Martins 1948: 237, figs 3, 4; Dutra et al. 1989: 73, 74, figs 8–12). Available names are *O. guaraunensis* de Oliveira, 1930; *O. tayoensis* (Reed) 1935 and *O. maricaensis* Martins, 1948, but all species require modern study based on large collections.

ACKNOWLEDGMENTS

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REFERENCES

AMOS, A.J., 1979. *Guia Paleontologica Argentina, Parte I: Paleozoico, Seccion V. Faunas Carbonicas, Seccion VI. Faunas Permicas.* CONICET, Buenos Aires. 158p.

ANTELO, B., 1972. Los braquiópodos del Carbonífero Superior de la Quebrada Larga, en las cabeceras del Río Blanco, Prov. de San Juan. *Ameghiniana* 9 (2): 159–172.

ARCHANGELSKY, A. & LECH, R.R., 1985. Presencia de *Cancrinella* aff. *farleyensis* (Eth. & Dunn) en las capas plegadas de la "Serie de Tramojo", Pérmico inferior de la Precordillera de Mendoza. *I Jornadas Geológicas de la Precordillera*, Acta 1: 187–191

ARCHANGELSKY, A. & AZCUY, C.L. 1985. Carboniferous palaeobotany and palynology in Argentina. *Actas del X Congreso Internacional de Geología y Estratigrafía del Carbonífero*, Madrid, 1983, 4: 267–280.

ARCHANGELSKY, A. & ARCHANGELSKY, S., 1987. Tafoflora de la Formación Tramojo, Paleozoico Tardío, en la región de Uspallata, provincia de Mendoza, República Argentina. *Ameghiniana* 24(3–4): 251–256.

ARCHANGELSKY, S. (ed.) 1987. *El Sistema Carbonifero en la Republica Argentina.* Academia Nacional de Ciencias, Cordoba, 383p.

ARCHANGELSKY, S., (ed.) 1996. *El Sistema Permico en la Republica Argentina* y en la Republica Oriental del Uruguay. Academia Nacional de Ciencias, Cordoba, 417p.

ARCHBOLD, N.W., 1981. *Lingula* (Lingulida, Brachiopoda) from the Late Artinskian (Permian), Carnarvon Basin, Western Australia. *Proceedings of the Royal Society of Victoria* 92(2): 169–180.

BIERNAT, G. & EMIG, C.C., 1993. Anatomical distinctions of Mesozoic Lingulide brachiopods. *Acta Palaeontologica Polonica* 38: 1–20.

BRUGUIÈRE, J.G., 1797. Vers, Coquilles, Mollusques et Polypiers. Tableau encyclopédique et methodique des trios rêgnes de la nature. Agasse, Paris. Tom. 2, pls 96–314.

BUATOIS, L.A., MANGANO, M.G. & NETTO, R.G., 2001. Paleoecosistemas anactualisticos vinculados a la glaciacion gondwanica: evidencias en el Paleozoico Superior del Oeste de Argentina y sur de Brasil. *II Simposio Argentino del Paleozoico Superior, Resumenes*, Trelew, p.3.

COOPER, G.A. 1942. New genera of North American brachiopods. *Journal of the Washington Academy of Sciences* 32: 228–235.

DALL, W.H., 1870. A revision of the Terebratulida and Lingulidae. *American Journal of Conchology* 6: 88–168.

DAVIDSON, T., 1848. Memoire sur les Brachiopodes du Systeme Silurian superieur de l'Angleterre. *Societe Geologique de France, Bulletin, Serie* 2, 5: 309–338, 370–374, 2 pls.

DERBY, O.A., 1874. On the Carboniferous Brachiopoda of Itaituba, Rio Tapajos, Prov. of Para, Brazil. *Bulletin of Cornell University, Science*, 1(2):1–73, pls 1–9.

DE OLIVIERA, E., 1930. Fosseis marinhos na Serie Itarare no Esatado de Santa Caterina. *Academia Brasileira de Ciencias, Anais* 2(1): 17–21.

DE OLIVIERA, E., 1936. Um novo brachiopodo da Serie Itarare. *Notas Preliminares e Estudos do Servico Geologico e Mineralogico do Brasil*, 5: 8–10.

D'ORBIGNY, A., 1847. Considerations zoologiques et geologiques sur les Brachiopodes ou Palliobranches. *Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences, Paris.* 25: 193–195, 266–269.

DESSANTI, R.N. & ROSSI, J.J., 1950. Nuevos hallazgos de fósiles Carboníferos en la Quebrada de Uspallata. *Revista de la Asociación Geológica Argentina* 5(3): 149–158.

DUTRA, T.L., NETTO, R.C., NOWATZKI, C.H. & ANDREIS, R.A., 1989. Achado de Braquiopodes inarticulados (Discinidae?) na regiao de Gravatai (RS), consideracoes estratigraficas e paleoecologicas. *Acta Geologica Leopoldensia* No. 29, Vol. 12: 61–76.

EGOROV, A.N. & POPOV, L.E., 1990. Novyi rod lingulid iz nizhnepermskikh otlozhenii Sibirskoi Platformy. *Paleontologicheskii Zhurnal* 1990 (4): 111–115.

EMIG, C.C., 1986. Conditions de fossilisation du genre *Lingula* (Brachiopoda) et implications paléoecologiques. *Palaeogeography, Palaeoclimatology, Palaeoecology* 53: 245–253.

Emig, C.C., 1997. Ecology of inarticulated brachiopods. In *Treatise on Invertebrate Paleontology. Part H. Brachiopoda, Revised. Volume 1. Introduction*, R.L. Kaesler, ed., Geological Society of America Inc. and University of Kansas Press, Boulder & Lawrence, pp 474–495.

Emig, C.C., 2003. Proof that *Lingula* (Brachiopoda) is not a living-fossil, and emended diagnoses of the Family Lingulidae. *Carnets de Geologie / Notebooks on Geology, Letter* 2003/01:1–8.

Etheridge, R. & Dun, W.S., 1909. Notes on the Permo-Carboniferous Producti of eastern Australia, with synonomy. *Records of the Geological Survey of New South Wales*, 8: 293–304, 3 plates.

Feruglio, E., 1934. Fossili liassici della valle del rio Genua (Patagonia). *Giornale di Geologia, Anali del R. Museo Geologico di Bologna, Serie* 2, 9: 1–64.

Fossa Mancini, E., 1933. Hallazgo de Braquiopodos del genero *Orbiculoidea* en el Retico de la Patagonia. *Boletin de Informaciones Petroliferas*, 10(106): 371–382.

Frenguelli, J., 1945. Moluscos continentals en el Paleozoico superior y en Triasico de la Argentina. *Notas del Museo de La Plata, 10, Seccion Paleontologia* No 83: 181–204.

Gray, J.E., 1840. *Synopsis of the Contents of the British Museum*, 42nd edition. British Museum, London, 370p.

Hall, J. & Clarke, J.M., 1892. An introduction to the study of genera of Palaeozoic Brachiopoda. *Natural History of New York, Palaeontology*, 8(1): 1–367, 20 pls. Charles von Benthuysen & Sons, Albany.

Holmer, L.E. & Popov, L.E., 2000. Class *Lingula*ta. In *Treatise on Invertebrate Paleontology, Part H Brachiopoda Revised, Volume 2 Linguliformea, Craniiformea and Rhynchonelliformea (part)*, R.L. Kaesler, ed., Geological Society of America Inc. and University of Kansas; Boulder, Lawrence, pp 30–46.

Ifanova, V.V., 1972. Permskie brakhiopody Pechorskogo Basseina. In, Ifanova, V.V. & Semenova, E.G. *Srednekamennougol'nye i Permskie brakhiopody vostoka i severa Evropeiskoi chasti SSSR*. Nauka, Moskva, 72–161, 13 pls.

Keidel, J., 1939. Las estructuras de corrimientos paleozoicos de la sierra de Uspallata, provincia de Mendoza. *Physis* 14(46): 3–96.

Keidel, J. & Harrington, H.J., 1938. On the discovery of Lower Carboniferous tillites in the Precordillera of San Juan. *Geological Magazine* 75: 103–129.

Kowalewski, M., 1996. Taphonomic megabias in the fossil record of Lingulide brachiopods. In Brachiopods. *Proceedings of the Third International Brachiopod Congress, Sudbury, 2–5 September 1995*, P. Copper. & Jisuo Jin, eds, A.A. Balkema, Rotterdam, pp 145–150.

Lange, F.W., 1952. Revisao da Faunula Marinha do Folhelho Pasinho. *Dusenia* 3(1): 81–91, pl. 4.

Leanza, F., 1948. Braquiopodos y Pelecipodes carboniferos de la provincia de la Rioja (Argentina). *Revista del Museo de La Plata, Seccion Paleontologia* 3: 237–264.

Lech, R.R., 1990. Distribución de la fauna de braquiópodos de la Formación Agua del Jagüel (Carbonífero superior-Pérmico inferior), provincia de Mendoza, Argentina. *XI Congreso Geológico Argentino, Acta* 2: 15–18.

Martins, E.A., 1948. Fosseis Marinhos na Serie Marica, Estado do Rio Grande do Sul. *Mineração e Metalurgia* 12(71): 237–239.

Mendes, J.C., 1961. *Langella*, novo genero de Lingulideo da Serie Tubarao. *Bóletim da Universidade do Parana, Geologia* 5: 1–8.

Menke, C.T., 1828. *Synopsis methodica molluscorum generum omnium et specierom earom quae in Museo Menkeano adservantur*. G. Uslar, Pyrmonti, 91 pp.

Miloradovich, B.V., 1936. Nizhnepermskaya fauna ostrova Mezhdusharskogo (Yuzhnyi Ostrov Novoy Zemli). *Trudy Arkticheskogo Instituta* 37: 37–82, 4 pls.

Pinto, I.D., 1949. Contribuçao ao reconheeimiento de Novos Fosseis na Formaçao Marica (Afloramento Budo) (Notas Preliminares). *Universidade do Rio Grande do Sul, Faculdade de Filosofia, Publicacione* 2: 1–6, 1 pl.

Reed, F.R.C., 1927. Upper Carboniferous fossils from the Argentina. In *A Geological Comparison of South America* with South Africa, A.L. Du Toit, ed., Publication of

the Carnegie Institution of Washington 381: 129–149.

Reed, F.R.C., 1935. A new brachiopod from the Upper Carboniferous of Santa Catharina, Brazil. *Academia Brasileira de Sciencias, Anais*. 7(2): 201–202.

Rocha-Campos, A.C., 1967. The Tubarao Group in the Brazilian portion of the Parana Basin. In *Problems in Brazilian Gondwana Geology. Conselho Nacional de Pesquisas*, J.J. Bigarella, R.D. Becker & I.D. Pinto, eds, Curitiba, 27–102.

Rodland, D.L. & Bottjer, D.J., 2001. Biotic recovery from the end-Permian mass extinction: Behavior of the inarticulate brachiopod *Lingula* as a disaster taxon. *Palaios* 16: 95–101.

Rodriguez, E.J., 1966. Contribución al conocimiento geológico del Carbónico del extremo Sur occidental del Precordillera. *Acta Geológica Lilloana* 7: 303–331.

Taboada, A.C. 1998. Dos nuevas especies de Linoproductidae (Brachiopoda) y algunas consideraciones sobre el Neopaleozoico sedimentario de las cercanías de Uspallata, Argentina. *Acta Geológica Lilloana* 18(1): 69–80.

Williams, A., Carlson, S.J., Brunton, C.H.C., Holmer, L.E. & Popov, L.E., 1996. A supra-ordinal classification of the Brachiopoda. *Philosophical Transactions of the Royal Society of London* (Series B): 351: 1121–1193.

Wittenburg, P., 1910. Ueber einige Triasfossilien von Spitzbergen. *Trudy Geologicheskogo Muzeya imeni Petra velikago Imperatorskoi Akademii Nauk* 4(2): 31–39, 1 plate.

Yrigoyen, M., 1967. Geology of the Triassic formation of northern Mendoza area. *I International Symposium on Gondwana Stratigraphy and Paleontology. Asociación Geológica Argentina, guidebook* 1: 1–13.

TWO NEW BRYOPHYTES IN VICTORIA

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CARR, D.J., 2005. Two new Bryophytes in Victoria. *Proceedings of the Royal Society of Victoria* 117(2): 319–325. ISSN 0035-9211.

Two bryophytes are described, both new to Science and, as far as is known, endemic to Victoria. The first is a moss which is common on tidal salt flats. It has ribbon-like leaves only 5–9 cells wide but up to 10 mm or more long, which are exposed on the surface of the mud, cleistocarpic capsules without a peristome, and relatively large spores with a punctate surface. It is named as *Pottia taeniofolia*. The second is a diminutive, gemmiferous, leafy liverwort, a minor, but common component of bryophyte communities on tree bark. It is named as *Microlejeunea victoriensis*.

THESE two new species, one a moss, the other a liverwort, have hitherto been overlooked by bryologists partly on account of their diminutive size, partly because, in the case of the moss, of its unusual habitat. The original collections were made in the mid nineteen fifties by me and my wife (née S.G. Maisie Fawcett).

In August 1953, I accompanied a student excursion to Anglesea to study seaweeds. The excursion was supervised by the late Mrs (later Dr) S.C. Ducker and was based on the Rover Scout Hut loaned for the occasion by the then chief Rover Scout, Professor Bob Cherry. The route to the sea passed over a bare tidal mud flat, where on the first morning Mrs Ducker stooped to pick up a piece of the surface mud on which she had observed some green filaments, which she suspected to be a filamentous alga.

Later on, back at the temporary lab, she examined the specimen microscopically but discarded it stating that it was not an alga. I immediately took it up, determined to find out what it was and declared it to be a species of moss.

Evidently the plant is unusual in being adapted to withstand the inundation by sea water which occurs at the site at high tides; it is the first truly thalassic moss. My wife and I subsequently decided to search for it at other suitable coastal sites and discovered it again at Cannon's Creek, 3 miles west of Tooraddin, on Western Port Bay. We revisited this area several times during the spring months of 1954 and again in 1955. The site was bounded on the landward side by a zone of coastal tea-tree (*Leptospemum laevigatum*) from which, towards the sea, there was a zone of flat land occupied by a community of small ephemeral angiosperms, characterised by the insectivorous *Polypompholyx tenella* with occasional small fucoid sporelings. The moss did not occur at all in this zone, in which it is evidently unable to compete with the angiosperm vegetation, but only in the next, otherwise rather bare, seaward zone.

The plants are so minute that even to collect specimens it was necessary for one person to collect suitable samples of surface mud while the other used a dissecting microscope to examine them.The earlier samples collected in August had antheridia, and those in September archegonia, but mature sporophytes were not found until October.

When fresh, the miniature capsules were like red pinheads, scarcely emerging above the mud.

Unfortunately, the pressure of other duties prevented completion of the study. It was taken up again in August 2002 during my retirement from the ANU, when my bryophyte collections were returned to me from the Canberra Botanic Gardens. The specimens had by then become somewhat colourless, extremely brittle and difficult to work with.

Methods. The patches of dried mud were soaked for some days in fresh water, then small pieces were excised on to microscope slides. By teasing away the particles of soil the very small, almost stemless plants were revealed. Suitable specimens were mounted in glycerin jelly for examination uing a Nikon photomicroscope, and photographed on Kodak T400 film. Prints were made from which drawings were prepared. Measurements were made with a calibrated ocular micrometer.

(1) Pottia taeniofolia D.J.Carr, *sp. nov.*

Plantae parvae, gregariae, eleistoearpa. Peristomium nullum. Folia taeniformia. Sporae grandes (37–47 µm diam.) In solo limoso aestuarii ereseit.

Plants are gregarious on saline mud on eoastal (tidal) mud flats. Stems very small (up to 0.45mm), the first few leaves ovate, stem-elasping, ecostate 350 µm long.

Later leaves ribbon-shaped (Fig. 3E-F), the first, 7–9 cells wide, with eells 55 µm long, subsequent leaves narrower (40 µm and 5 -6 eells wide), up to 10 mm long, spreading on the surfaee of the mud. Under a lens, these ribbon-like leaves are seen to constitute a many-layered thateh of linear filaments completely obseuring the surfaee of the underlying mud (Fig. 3D). Leaf eells hyaline, laeking completely the verrueose eutieles of eertain other *Pottia* speeies. Periehaetial leaves (Fig. 3B) about six, stem elasping, up to 0.6mm long and 415 µm wide at their widest point, spathulate, mueronate, eostate, the eosta pereurrent. The basal eells of these leaves are differentiated in an inverted V-shaped zone extending to the nerve (Fig. 1B). This zone aseends narrowly almost to the tip of the pereurrent nerve. It has relatively large eells (80 µm by 40 µm). The eells of the edges and upper part of the leaf are uniform and c.30 µm by 20 µm.

The eleistoearpie eapsule (Fig 1B) is reddish when fresh, 0.9 mm long, the hollow, eurved seta (Fig. 3B) about 2 mm long, 75 µm wide ensheathed at its base by the vaginula (tissue derived from the base of the arehegonium, as in *Pottia lanceolata* C.M., illustrated by Goebel (1915–18; fig. 812). The eapsule is ovoid with a prominent rostrum (0.2 mm long). The ealyptra elosely ensheaths the rostrum and upper part of the eapsule and is not split longitudinally, nor is it shed after eapsule dehiseenee. There is no peristome. There are about six stomata on the apophysis of the

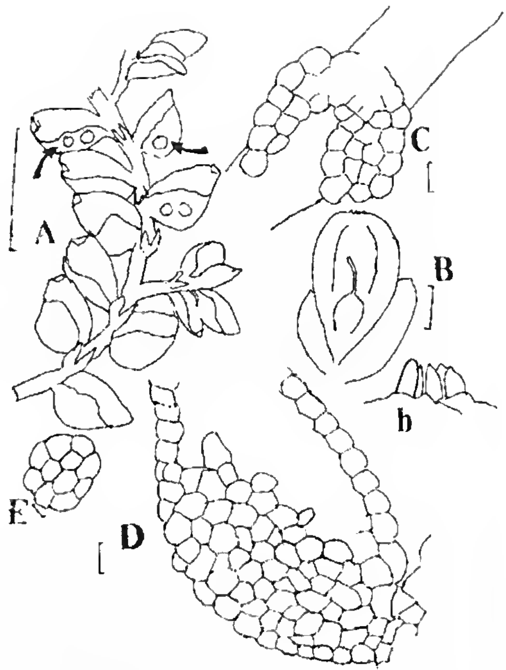


Fig 2. *Microlejeunea victoriensis* A. Whole plant. Arrows indicate immature gemmae within the fold of the postical lobe of the leaf. Scale bar, = 1 mm. B, female perianth, somewhat immature Scale bar = 100 µm. b, rostrum of perianth. C, underleaf. Scale bar = 10µm D, Postical lobe of leaf showing the papillae on its free edge. Scale bar = 10µm. E. Transverse section of stem, Scale bar = 10 µm

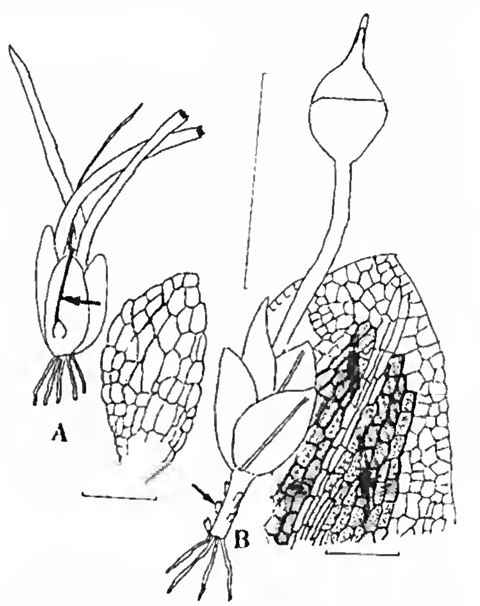
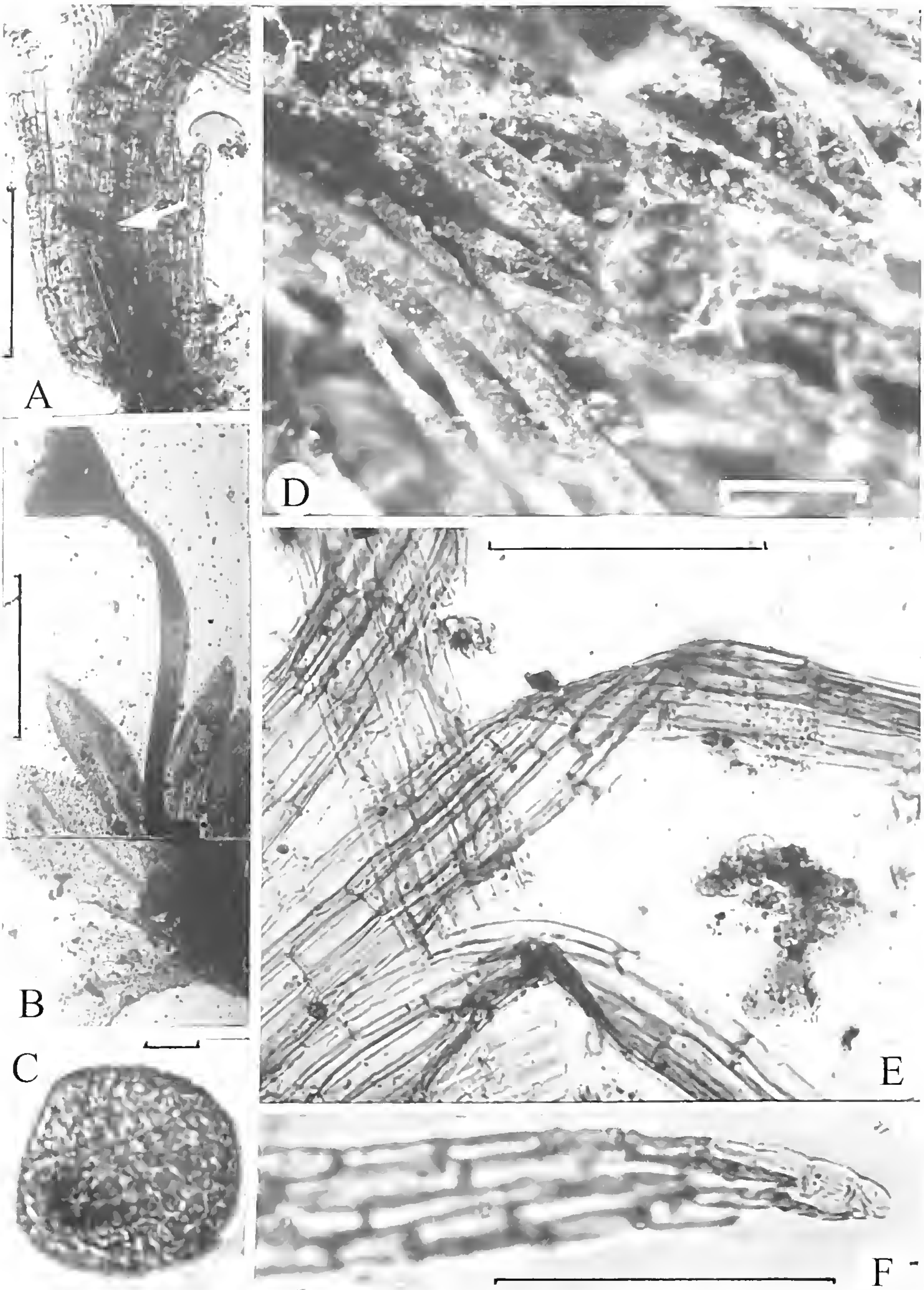


Fig 1. *Pottia taeniofolia*. A, B. whole plants. A Gametophyte phase, arrow indicates archegonium, B Sporophyte phase, arrow indicates bases of shed ribbon-like leaves. Vertical scale bar=10 mm refers to whole plants At A, a basal ecostate leaf. At B a perichaetial leaf, showing the inverted-V zone (shaded) of enlarged cells extending towards the tip of the nerve. Horizontal scale bars = 100 µm. refer to the two leaves.

Fig 3. *Pottia taeniofolia*. A, Gametophytic plant with an archegonium (arrowhead) B, Sporophyte with dehisced capsule. Scale bars for 1& 2 =1mm. C, Spore. Scale bar =10 µm D, E, F, Ribbon-like leaves, Scalebars = 100 µm. D, seen by dissecting microscope at the mud surface. E and F by transmission light microscopy. F, leaf tip.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capsule. The spores (Fig. 3C) are relatively large (37 -47μm in diamerter), larger in some specimens than in others. and some at least are discoid (20 μm deep). The spore surface is minutely punctate all over and also shows tetrad markings.

Holotype. Cannon's Creek, Victoria 29.10 1955, by D.J.and S.G.M. Carr to Herb Melb.

Isotypes: Cannon's Creek (same date and collectors) herb NSW, Herbarium of the Aust.Nat. Bot.Gard., Canberra and the author's herbarium.

Discussion. The new moss is placed in the Genus *Pottia* since it shares a number of characters with other species in that genus. Many of the British and European species of *Pottia* are found only in maritime localities and are generally described as halophytic e.g. *P. heimii*, *P. crinita P. salina*, *P. propagulifera*, *P. commutata* (Dixon, 1924; Gams, 1932). Although none are reported from saline mud. In Australia, *P. drummondii* is described by Scott and Stone (1976) as occurring on clay-pans and salt marshes, and they also refer to an undescribed species from saline clay near Dimboola, around alkaline lakes. At Cannon's Creek there were small patches also of the mosses *Ditrichum difficile* and *Pottia drummondii*, which Catcheside (1980) suggests is synonymous with the New Zealand P. maritima, found in salt marshes. But *P. taeniofolia* is by far the dominant species in the area.

Many *Pottia* species are cleistocarpic or lack a peristome, and the rostrate capsule is borne on a short, often curved seta. All are very small and gregarious with a very short stem. In most the perichaetial leaves have an inverted V-shaped zone of relatively large, differentiated cells. The spores are relatively large with a warty or granular surface (Catcheside, 1980).

The description given above has been drawn up from specimens collected nearly fifty years ago, all parts of which have become extremely brittle with the passage of time. Several questions remain unanswered. It seems probable that the ribbon-shaped leaves grow by a basal meristem, which, initially, may be only one or two cells wide. This is suggested by the fact that the ribbon leaf-tip tapers to a point consisting of only 1 or 2 cells (Fig. 3F). The ribbon leaves are extremely readily detached in handling the dry specimens. These leaves, like the first ecostate basal leaves, may even be shed naturally, leaving a length of bare lower stem (Fig. 1B) during the formation of perichaetial leaves and fructification. Certainly the archegonia are fully formed while the ribbon leaves are present (Fig. 1A, Fig. 3A) and while the first perichaetial leaves are only primordial. The occurrence of stomata on the apophysis indicates the presence of assimilatory tissue. This may be regarded as an adaptation compensating for the loss of the suite of ribbon-like leaves. Stomata have not been reported from the sporophyte of any previously described species of *Pottia* (Goebel 1916–18, p. 882–884; Catcheside, 1980). It remains undecided whether the gametangia are borne on the same or on different plants. To resolve these questions it would be desirable for new and fresh specimens to be collected and studied from existing localities, a task that I must now leave to a new generation of bryologists.

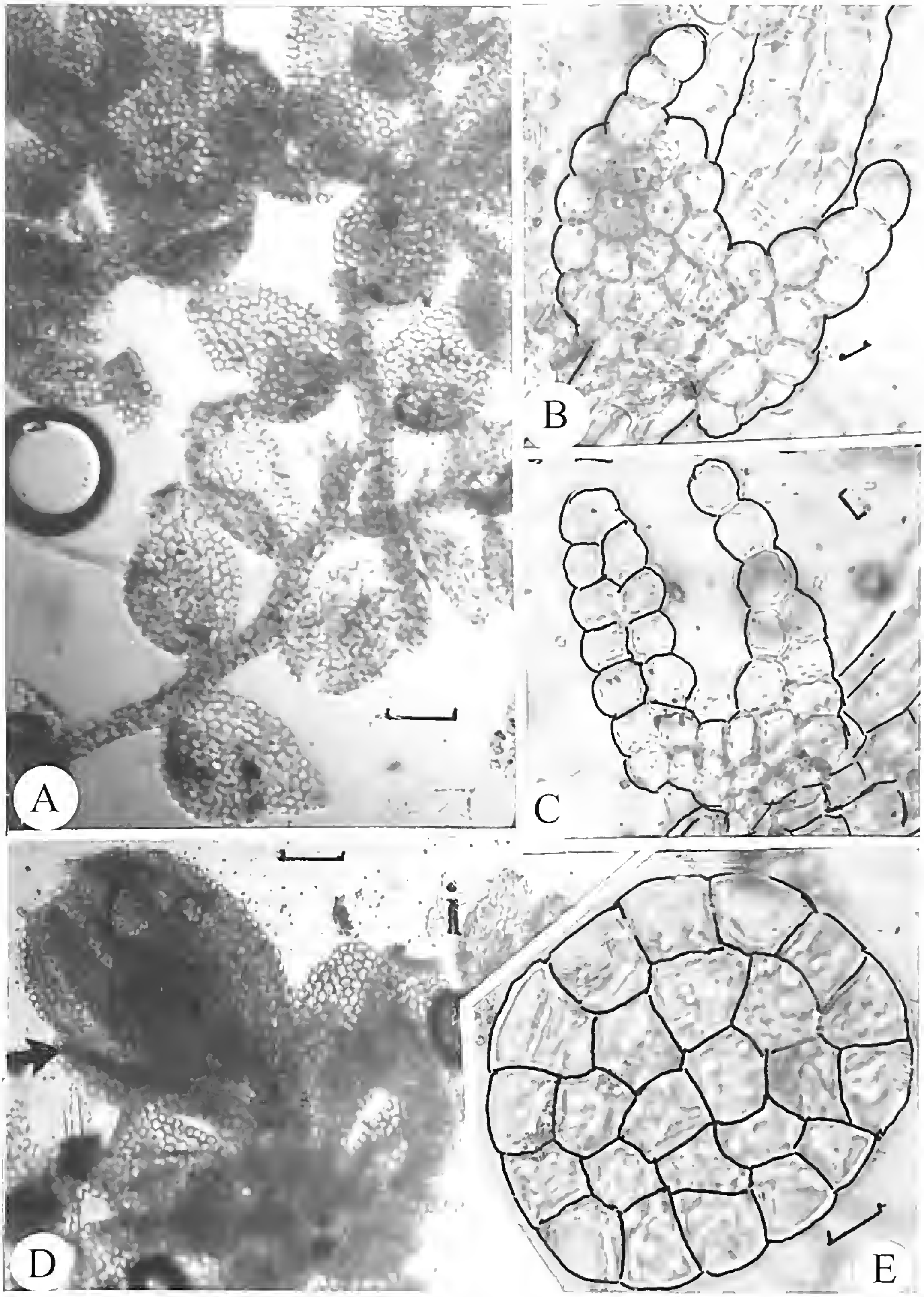
I have not visited the possible sites of occurrence at Port Albert or Corner Inlet, nor the flats of the Glenelg River estuary.

(2.) Microlejeunia victoriensis D.J.Carr, sp.nov.

Plantae parvae, solitariae. Foliorum lobi postici quam antici 2–3plo breviores. Foliorum inferorium lobi angusti (1 vel 2 [3] cellulis lati), non vel moderate divergentes. Gemmae presentes. In cortice arborum (*Banksia*, *Allocasuarina*, *Acacia*) aliis brophytarum creseit.

Plants sparse, solitary, very small, up to (but rarely) 5 mm long. Pale green, translucent, creeping, on the bark of rough-barked trees, in association with other bryophytes, especially *Frullania probosciphora*. Branching irregular. Stems not sinuate, with 3 medullary cell rows and 6–8 cortical cells (Fig 2E) 50μm wide. Leaves not imbricate, somewhat distant from each other. Antical lobes ovate, acuminate, 250μm long by 165 μm wide, the tips incurved (Fig 2A). Leaf cells thin-walled, 22μm wide, without trigones or thickened cell walls, with 1–10 minute oil bodies per cell, sometimes in a chain of 7–10. The postical lobes (=lobules) half to one third the size of the antical lobes (=lobes), larger in immature leaves, 225μm long by 100 μm wide, the curved free edge equipped with 2–4 small papillae, each 1–2 cells high (Fig. 2D).

Fig 4. *Microlejeunea victoriensis*. 1 Fragments of 4 plants. Scale bar =100 μm. 2. and 3, Underleaves. 4 Female perianth, somewhat compressed. arrow, perichaetial leaf, i=innovation. 5. Mature gemma. Scale bars for 2–5 =10 μm.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Amphigastria (=underleaves) (Fig 4B-C) narrowly ovate, 145 x 85 µm deeply incised, not or only moderately divergent, and only very rarely as much as 45o, 1–2 (rarely 3) cells wide, often terminating in a single cell. Rhizoids few.

Mature gemmae (Fig. 4E) ovoid. discoid, 75µm long, 50µm wide, multicellular, initially housed within the postical lobe, especially of leaves near the shoot tip (Fig. 2A). The discoidal gemmae lack an obvious apical cell or an attachment cell or cells. Perianth obovate, 5-plicate, up to 600 µm long, 410µm wide, vey shortly rostrate, the rostrum consisting of a group of single cells (Fig. 2b). Perianth (Fig. 4D) borne at the tip of the stem and succeeded by an innovation from the subjacent stem. Perichaetial leaves about half as long as the perianth, underleaves larger than those on the vegetative stem. Antheridial branches very sparse, very short, almost sessile, perichaetium spherical 175–185 µm diameter. Antheridial branches have been seen only on one specimen and further information on them is necessary.

Holotype. D.J. Carr and S.G.M Carr, on the bark of trees (*Banksia serrata*) at Wilsons Promontory. Victoria. November 1954. Herb. Melb.

Isotypes. B.M.Nat.Hist, Herb, NSW, and Herb. of the Aust.Nat.Bot.Gard., Canberra

Disenssion. This plant is a very minor component of common epicortical bryophyte communities on the trunks and branches of trees (*Allocasuarina verticullata, Banksia serrata*). It would appear to be fairly common, as we have found it on trees at Anglesey (*Acacia melanoxylon*), Gembrook, and Kallista and at Wilsons Promontory (on the bark of trees of *Allocasuarina* and *Leucopogon* as well as *Banksia*). It may have been confused with the larger *Harpalejeunea latitans*, which also has acuminate leaves with incurved tips, and with the lobes of the amphigastria 1–2 cells wide. However that species has the lobes of the amphigastria always widely divergent, and also has ocelli at the base of the antical lobes and lacks both gemmae and the special papillae on the free edge of the postical lobe. The only other small *Lejeunea* found on tree bark in Victoria is *Nephelolejeunea hamata* (not illustrated in Scott, 1985) which lacks gemmae and has only one 2-celled tooth on the postical lobe and underleaves with widely divergent, blunt lobes. None of the 73 species of *Microlejeunea* described in Stephani (1912–1917, Vol 5, p. 806–840) has gemmae. Discoidal gemmae occur in various Lejeuneaceae especially those which grow in elevated habitats such as on the bark of trees (Schuster 1984, p. 848). *M. victoriensis* has few rhizoids and lacks totally the "holdfast organs" ("Haftorgane") (formed from fastigiate rhizoids) which are a prominent feature of *Frullania probosciphora* with which it is often associated.

Schuster (1963. p, 246) says that he "retains a conservative delimitation of *Microlejeunea*" while claiming that Bischler et al (1962) is "singularly unconvincing" due to "a series of errors". Mizutani (1962) "does not give *Microlejeunea* the status of a subgenus!" In fact Mizutani not only reduced Taylor's *Microlejenna punctiformis* to *Lejennea*, despite admitting that specimens had many times been misidentified as *M. ulicina*, a species used to typify the genus *Microlejeunea* but (*loc cit* p. A199) says "I think *Microlejeunea* is an artificial genus". According to Schuster (1963, p. 207), the taxon is a subgenus of *Lejeunea* characterised by the stems having 3 rows of medullary cells, often dioecious, small and with remote, usually sub-erect leaves, underleaf lobes usually 2–3 (4) cells broad, sometimes ocellate. Apart from the "sub-erect" nature of the leaves (evidently a matter of degree), *M. victoriensis* fits these criteria. Bischler et al (1962) include in *Microlejeunea*, taxa with "stems usually sinuate", with "leaves with insertion with the axis of the leaf parallel or nearly so to the stem" and the lobule reaching 0.4–0.8 of the area of the lobe in "well-developed leaves". Their typification is disputed by Schuster (1963b, p. 249) and is certainly not largely applicable to *M.victoriensis*. Bischler et al (*loc cit.*) maintain that *Microlejeunea* species lack ocelli, as does our new species. The only other *Microlejeunea* species reported from Victoria is *M. primordialis* (Hook f. et Tayl.) which is reduced to *Lejunea primordialis* without explanation by Scott (1985, p. 187), perhaps influenced by Mizutani, whom he cites as an authority on generic distinctions in the family, but see Carr, 2004. According to Scott (*loc cit*), *M.primordialis* has "evident trigones and intermediate (cell wall) thickenings throughout the leaves". It appears from Scott, who found it only once, to be rather rare in Victoria. Schuster (1963b, p. 248) suggests that it is conspecific with *M. aucklandica* in New Zealand. Both species are ignored by Miller et al (1962).

Our knowledge in Victoria of the immense family *Lejeuneaceae*, which has more than 60 genera and sub-genera (Schuster 1983c, p. 587) and 2000 species of world-wide occurrence (Mizutani 1983, p 118. Stephani 1912–1917) is poor. The determina-

tion of the taxonomic status of specimens is fraught with difficulties, and synonymy abounds. The resident Victorian hepaticologist, Mr Pat Bibby, who died in June 1955, usually declined to determine specimens further than to the family, *Lejeuneaceae*.

The treatment of the family at the end of the otherwise excellent treatise on liverworts by Scott (1985) is somewhat perfunctory, and the critical illustrations few. Generic distinctions not found in Scott (1985) are available in Schuster (1963a), a reference omitted from Scott's list.

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I am grateful to Professor Hermann Persson of the Riksmuseets Paleobotanica, Avdelning, Stockholm, Sweden, and to Dr (later Professor) Peter Greig-Smith (the Universities of Manchester and Bangor, North Wales) for encouraging my early interest in bryology and to Prof. Persson for sending me copies of the unpublished Icones (illustrations, Southern Hemisphere species) to the *Index Hepaticarum* of Stephani. I am also grateful to the Director of the Hattori Botanical laboratory, Miazawa, Japan, for the gift of specimens and help in accessing the relevant literature. I thank Mr Peter Zelman, Lyons ACT, for access to photomicroscopy and Mr Roland Jahnke, who in 1982 discovered a new locality for the moss near the mouth of the Bass River. and Mrs. Janette Lenz (both ACT) for their encouragement and interest and to Mr A.S. George, WA. for the Latin diagnoses.

Note: *Lejeunea fawcettiae* (Carr 2004) Holo. (Carr, S.G.M. 357) Melb., Iso. B.M.Nat.Hist., Para (Carr & Carr 157) Melb.

REFERENCES

Bischler, H., Miller, H.A. & Bonner, C.E.B., 1962. Studies in Lejeuneaceae.4. The typification of *Microlejeunea*. *Nova Hedwigia*, 4:173–187.

Carr, D.J., 2004. Lejeuneaceae (Hepaticae) of Victoria; Additions and a restitution. *Proceedings of the Royal Society of Victoria* 116(2): 221–232.

Catcheside, D.G., 1980. *Mosses of South Australia*. Govt Printer. South Australia, 12/12/1980.

Dixon, H.N., 1924. *The Student's Handbook of British Mosses*. 3rd Edition, London: Wheldon & Wesley, Ltd., London.

Gams, H., 1932. Bryo-cenologies; (moss societies) Chapter 12 pp. 323–366. In *Manual of Bryology*, Fr.Verdoorn, ed., Martinius Nihoff, The Hague.

Goebel, K., 1915–1918. *Organographie der Pflanzen* 2nd Edition Vol 2. Spezielle. Organographie. G. Fischer, Jena.

Miller, H.A., Bonner, C.E.B. & Bischler, H., 1962. Studies in Lejeuneaceae. 5 *Microlejeunea* in Pacific Oceania. *Nova Hedwigia*. 4(3–4):551–561, pls 129–131.

Mizutani, M., 1962. A revision of Japanese Lejeuneaceae. *Journal of the Hattori Botanical. Laboratory*. 24: 115–302. Figs 1–39.

Schuster, R. M., 1963a. An annotated synopsis of the genera and subgenera of Lejeuneaeae. *Nova Hedwigia. Beihefte*. 9: 7–203

Schuster, R. M., 1963b. Studies on antipodal Hepaticae. 1. Annotated keys to the genera of antipodal hepaticae with special reference to New Zealand and Tasmania. *Journal of the Hattori Botanical Laboratory*. 26: 185–309.

Schuster, R. M., 1983c. Phytogeography of the Bryophyta. Ch 10. In *New Manual. of Bryology*, Vol.1. R.M Schuster, ed., Hattori Botanical Lab., Miazawa, Japan, 463–626.

Schuster, R. M., 1984. Comparative anatomy and morphology of the Hepaticae. Ch.14. In *New Manual of Bryology*, Vol.2. R.M Schuster, ed., Hattori Botanical Lab., Miazawa, Japan, p 760–891.

Scott, G.A.M., 1985. *Southern Australian Liverworts* Australian Flora and Fauna Series. 2. Australian, Fed. Govt. Publ. Service, Canberra

Scott, G.A.M. & Stone, I., 1976. *The Mosses of Southern Australia*. Academic Press, London, N.Y.

Stephani, F., 1912–1917. *Species Hepaticarum*. 7 vols. Georg & Co. Geneva & Basel.

CORRIGENDA

FOR

VOLUME 116

EXPLANATORY NOTES

The corrigenda published here are for the following papers:

THE YOUNG VOLCANIC REGIONS OF SOUTHEASTERN AUSTRALIA: EARLY STUDIES, PHYSICAL VOLCANOLOGY AND ERUPTION RISK

Bernard Joyce

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The young volcanic regions of southeastern Australia, known as the Newer Volcanic Province, can be divided into four main subprovinces. The Western Plains subprovince and the Mt Gambier subprovince in southeastern South Australia occupy broad plains, while the Western Uplands subprovince is the elevated east-west spine of Western Victoria, with the Great Divide running along its crest. Small areas of youthful volcanism are also found in the Eastern Uplands subprovince.

Beginning about 6–7 Ma ago, but mainly since 5 Ma, a new volcanic province formed on both the Uplands and the Plains, and nearly 400 small, monogenetic scoria cones, maars and lava shields have been built up by Strombolian/Hawaiian eruptions. Fluid basalt flows have spread laterally around vents, often for many tens of kilometres down river valleys. Where the lava flows have blocked drainage, lakes and swamps have formed. Phreatic eruptions have deposited ash and left deep craters, often now with lakes. The study of the province began in 1836, and now, over a century and a half later, while the cause of activity still remains unexplained, future activity is believed to be likely.

Keywords: volcanology, exogenic landscape, history, catalogue, dating, eruption risk, Australia.

ERUPTION RISK

If activity in the Newer Volcanic Province (NVP) (See Fig. 1) had been regularly spaced over time, simple arithmetic (400 volcanoes in 5 Ma) would suggest there had been an eruption every 12,500 years. The most recent eruption which has been dated is Mt Gambier, at 4000–4300 B.P. (Blackburn et al. 1982), so on that basis we are well within the possible period for future activity.

Some lava flows have been dated by K/Ar, radiocarbon, and other isotopic techniques, but others have not. A more detailed chronosequence of lava flows, cones and craters can be built up by studying the changes in landforms, drainage, soil and regolith over time, using field mapping, air photos and satellite imagery, and new airborne geophysical imagery (Joyce 1999). Such work is helping assign ages to otherwise undated flows, and we seem to be seeing cycles of activity through time, notably a period of more concentrated activity in the late Quaternary in far Western Victoria (Joyce 2001a). Perhaps a dozen volcanoes may have erupted within the last 20,000 to 30,000 years — this would be an eruption every 2,000 years or so. However if vents were clustered into groups erupting about the same time, as seems likely, there may have been somewhat longer periods between each group of volcanoes.

Future eruptions

Australian volcanologists agree that further eruption is possible (Blong 1989), and may well be overdue. A future eruption would not be the renewal of activity at an existing volcano, but the initiation of a new volcano. The pattern of age distribution in the NVP can be used to suggest where a future eruption is most likely (Fig. 2).

Little warning of an eruption would be expected. Minor seismic activity with small earthquakes might precede the eruption by some weeks, and there could also be minor uplift or subsidence of the ground surface, and perhaps changes in ground temperature, and the exhalation of volcanic gases and steam.

The types of eruption to be expected are:

- maar crater formation by phreatic eruption, with radial base surge ash flows, and ash falls for several kilometres downwind i.e. to the east;

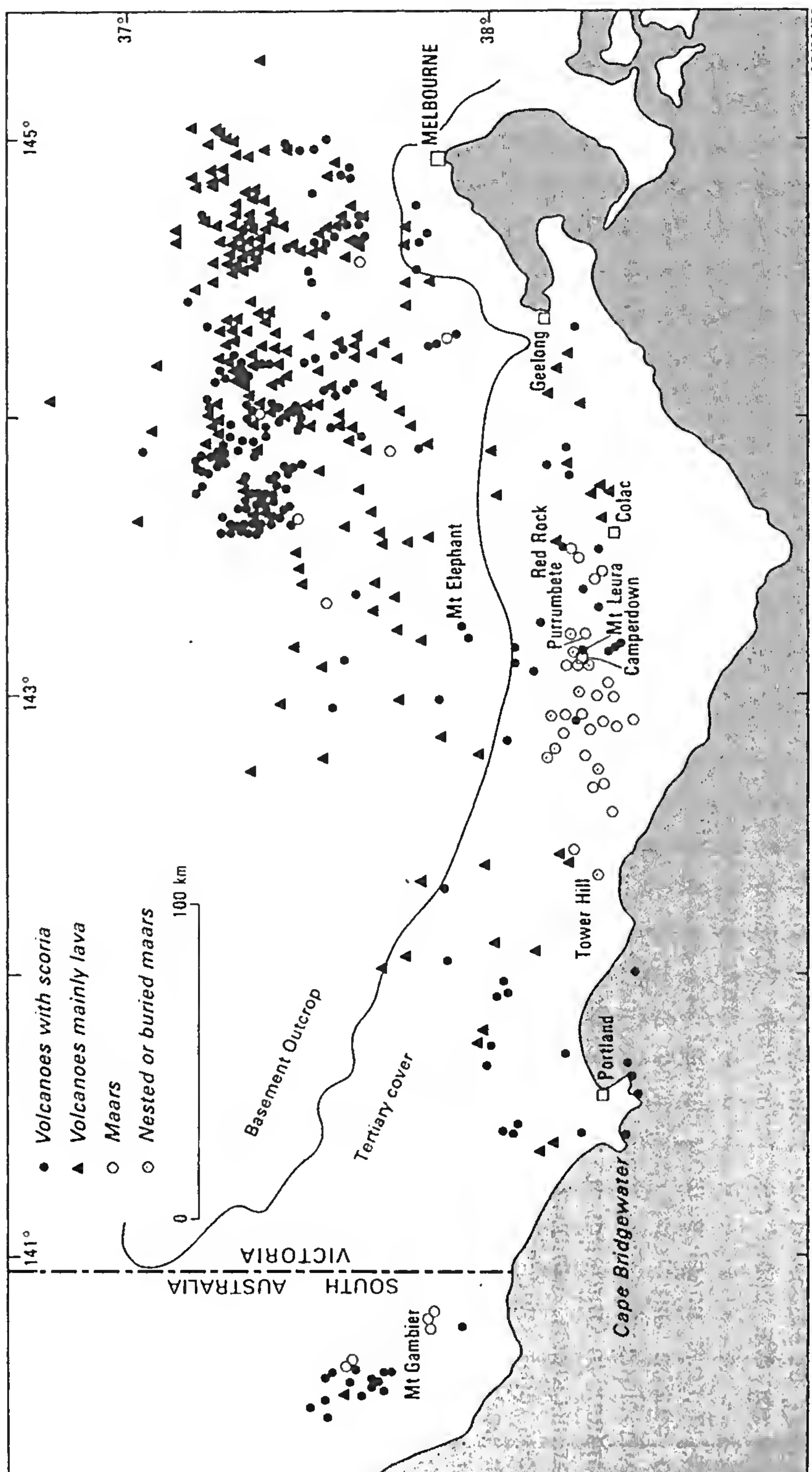

Fig. 1. Volcanoes of the main parts of the Newer Volcanic Province by type, based on Joyce 1975 (Johnson 1989)

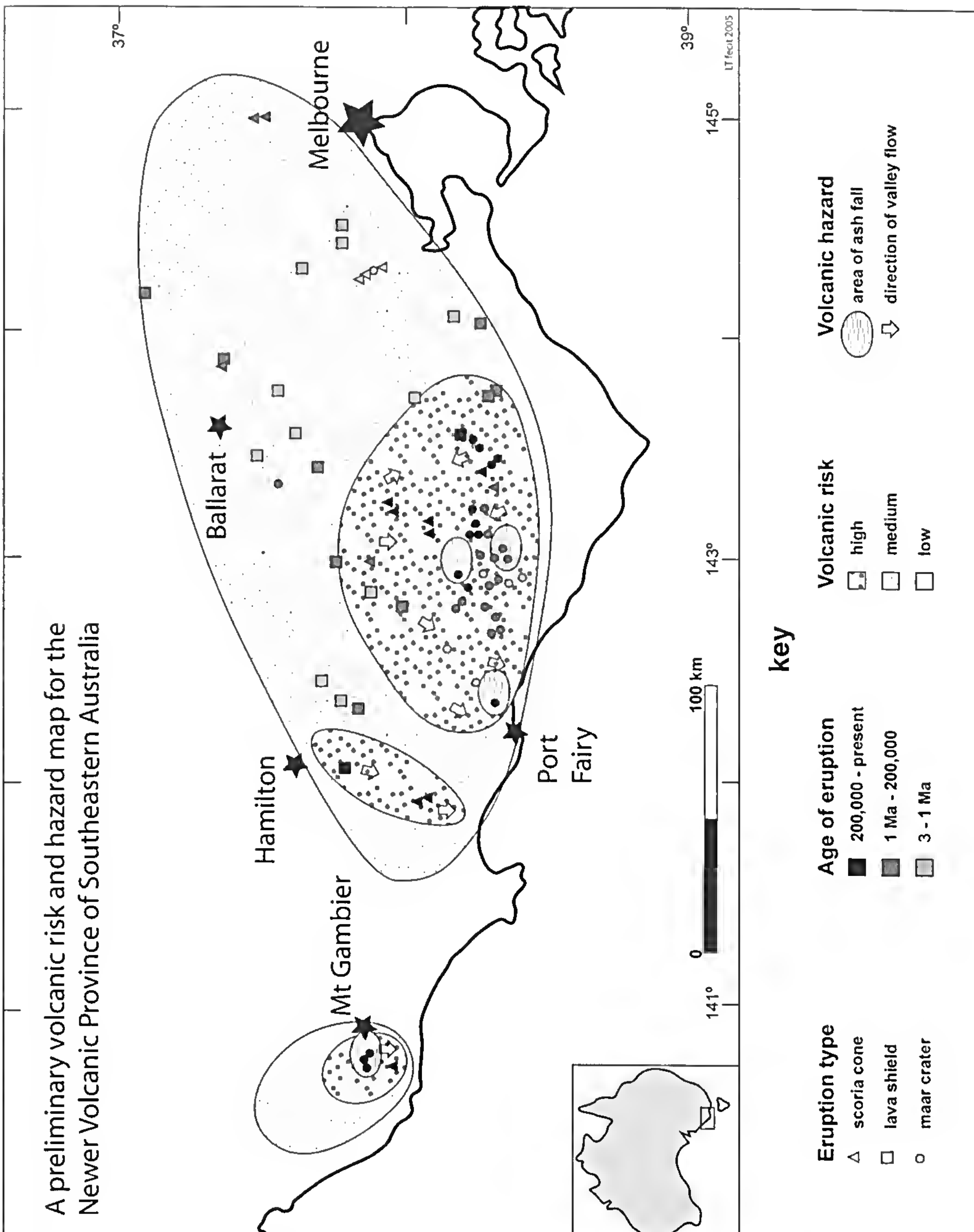

Fig. 2. Mapping of eruption types and ages with an indication of volcanic risk and hazard for the Newer Volcanic Province (after Joyce 2001a)

- cinder/scoria cone formation by fire-fountaining; and
- lava shield building and associated long valley flows.

Field studies have shown that these three types may occur separately, or in combination. For example an initial maar eruption may be followed by cone building within the maar crater (Tower Hill), or a series of lava flows and the building of a lava shield may be followed by scoria cone formation (Mt Napier).

Such activity might last for weeks or months, or for some years. If vents are clustered, successive eruptions, perhaps of different types, may occur near an initial eruption site, thus affecting a wider area for a longer period. Fumarolic activity and minor gas and ash eruption may continue for many years after the end of the main eruptions.

Maar activity upwind of a town or one of the major cities of the region, such as Melbourne or Ballarat, would provide particular problems from ashfall and base surge flows. In contrast, lava flows would follow the general slope and mostly move southwards down pre-existing valleys (Fig. 2). Hazard impacts of lava and ash would include property and infrastructure damage; effects on people, farm animals and crops; water pollution and stream derangement; and grass and forest fires. There could be associated earthquakes and ground deformation. Emergency management would be concerned with evacuation planning, diversion or control of flows, removal of ash and scoria from roofs and roads, control of fires and floods, and the repair and rebuilding of infrastructure, especially roads and bridges (see discussion in Blong 1984). A risk and hazard map (such as in Joyce 2003) can suggest where a future eruption might occur (Fig. 2). Government bodies should plan for preparedness and mitigation, and eruption scenarios should be developed and publicised. Public education will be necessary, both within the local community, and for planners within local government and emergency organisations (Joyce 2001b).

FUTURE STUDIES

Intraplate volcanism is widespread around the world, but a major problem is explaining why such activity occurs. The detailed information now available for the NVP makes it an ideal region to attempt to solve this problem (see discussion in Price et al. 2003, Cas 1989, Johnson 1989).

The geological heritage values of the NVP are well documented (Joyce & King 1980, Joyce & Webb 1993) and can provide an important way of promoting hazard and risk concepts to the local inhabitants (Joyce 2001b). Recent threats to this heritage, which is of national and international significance, include quarrying (Mt Leura), housing development (Lake Gnotuk, Mt Aitken) and landform destruction (Byaduk lava flow from Mt Napier). New reserves have however been developed at Mt Elephant and Mt Rouse volcanoes, and there have been recent improvements to interpretation at other sites (Mt Leura, Byaduk flow), and the development of the Volcanic Trail across much of Western Victoria. A recent National Trust landscape study of the Stony Rises, and the establishment of the Volcano Discovery Centre at Penshurst, near Mt Rouse volcano, are also promising developments. In the future the integration of volcanic research, local history study, and heritage interpretation could be the key to developing a greater awareness, not just of heritage values, but also of volcanic risk and hazard in the Newer Volcanic Province of southeastern Australia.

ACKNOWLEDGEMENTS

Local and overseas colleagues, and many research students, have worked on aspects of the Newer Volcanic Province, and their ideas have emerged in publications, theses and lectures. Ideas have also developed in the field, and sometimes later in the pub. Cliff Ollier introduced me to the NVP and we have published papers together. The many Honours students who have mapped and described individual volcanoes over the past 30 years have helped continue my education. I thank Chris Turney and Jim Peterson for valuable comments on the final draft of this paper. And I gratefully thank Peter Kershaw for his enthusiasm in getting it all to fruition.

GEOLOGY AND GEOMORPHOLOGY OF THE LADY JULIA PERCY ISLAND VOLCANO, A LATE MIOCENE SUBMARINE AND SUBAERIAL VOLCANO OFF THE COAST OF VICTORIA, AUSTRALIA.

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Fig 1: Locality map.

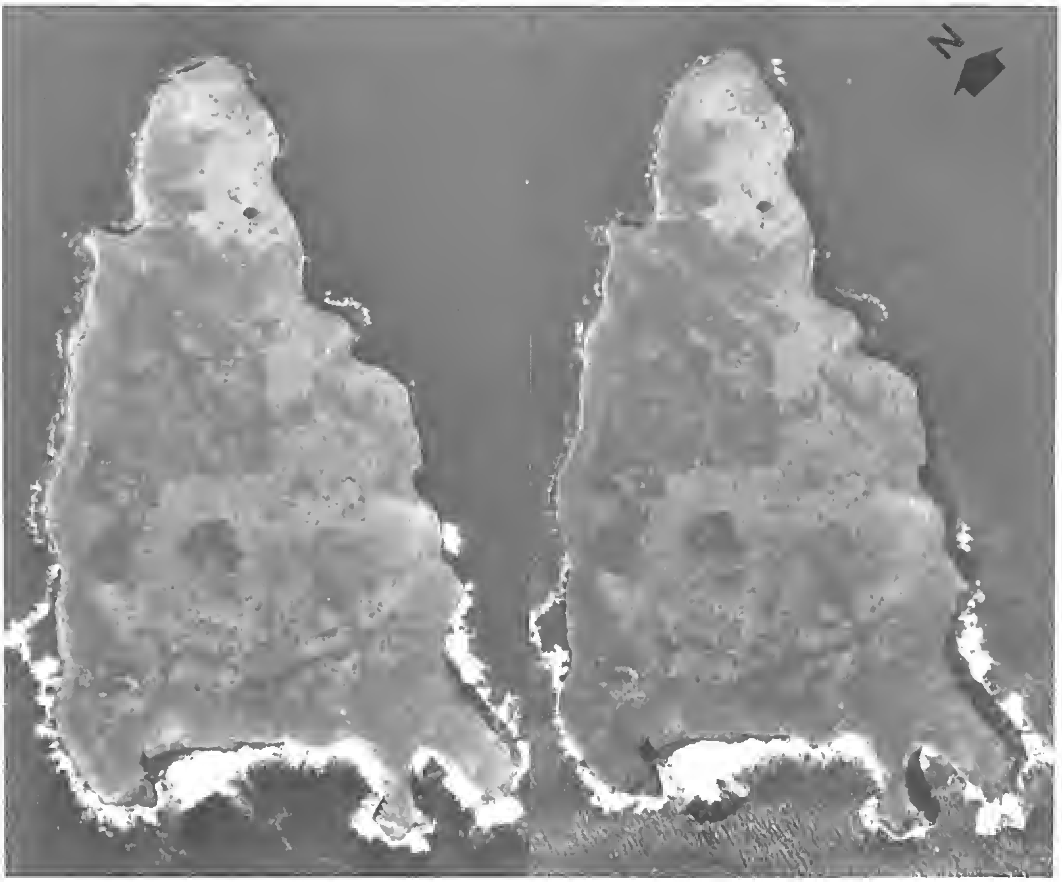

Fig 2: Stereographic air-photos, Lady Julia Percy Island. The remnants of a vent are exposed in the cliffs of the goose-necked promontory of Pinnacle Point (bottom-right), the highest point on the island at 46m. This point is separated from Thunder Point (bottom-right) by Horseshoe Bay, a deeply-incised cove. The prominent palaeo-wave-cut McCoy Platform (bottom-left) lies just west of Seal Bay. Dinghy Cove, the usual access to the flat plateau on the island, is the sheltered bay at top-left.

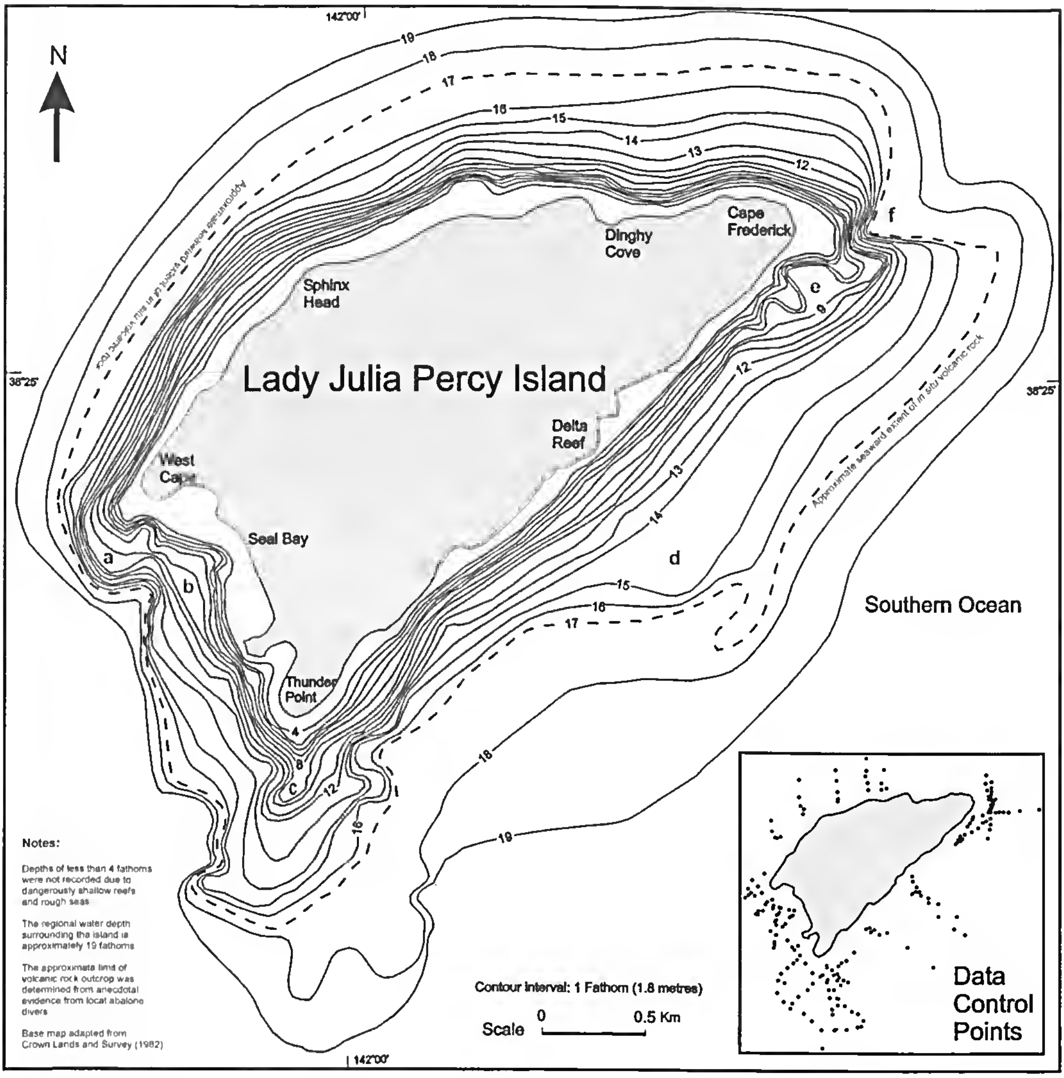

Fig. 3. This bathymetric map highlights the formation of the present Lady Julia Percy Island due to differential modification of the original volcanic delta. The northern edge of the seamount rises consistently and moderately steeply from the sea floor. In contrast the southern edge has been more greatly modified by prevailing southwesterly weather systems. Geomorphic features near West Cape (a), Seal Bay (b), Thunder Point (c) and Delta Reef (d) are interpreted to be submerged wave-cut platforms. The submerged bench and steep slope east of Cape Frederick (e and f) are more sheltered and may therefore be primary volcanic features.

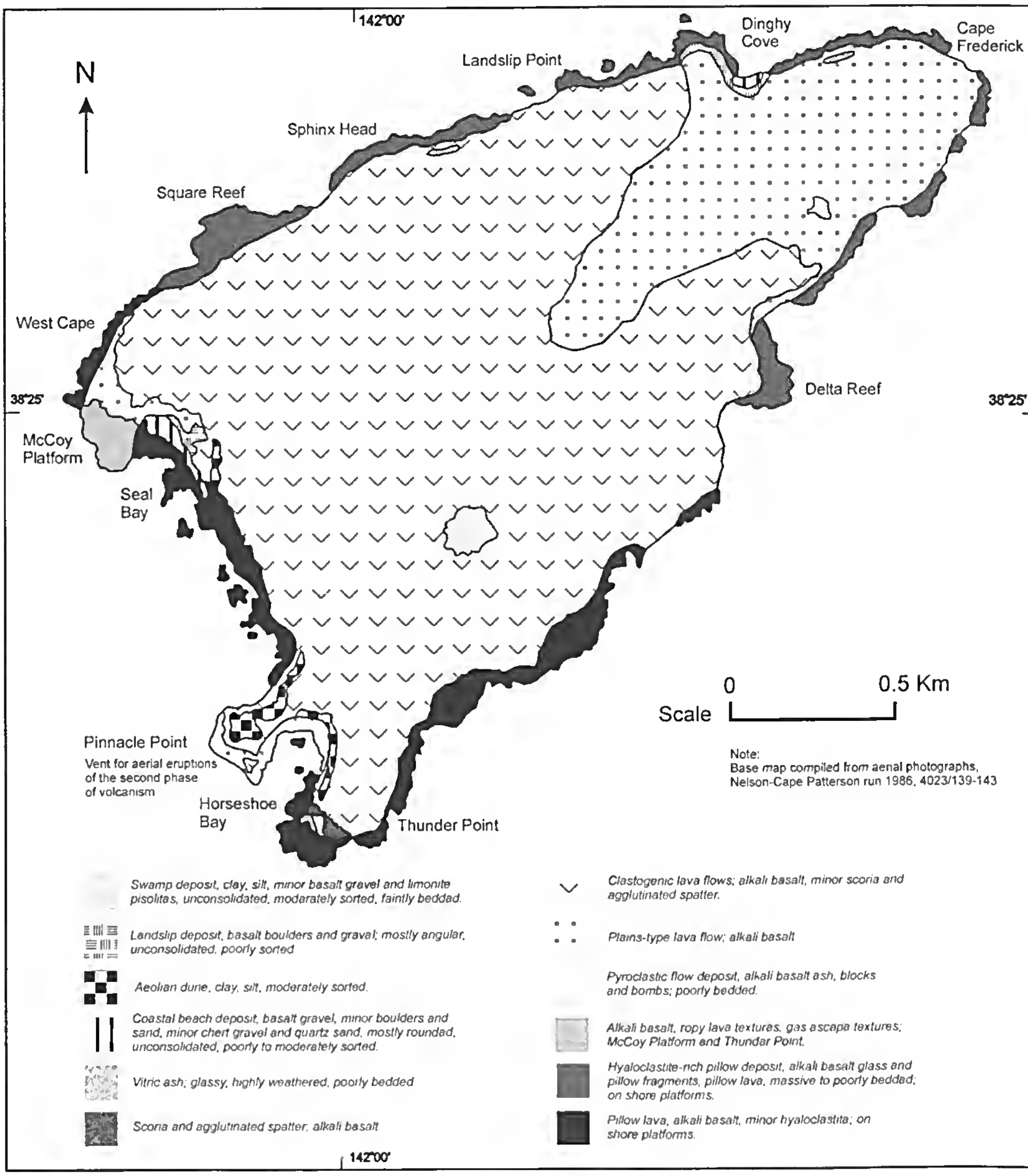

Fig 4: Geology of Lady Julia Percy Island.

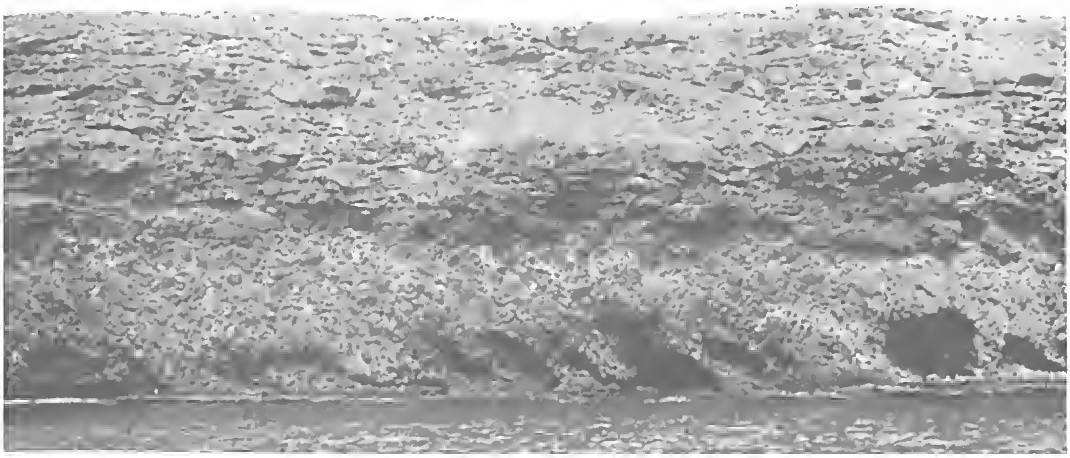

Fig 5: NW view of the southern coastline between Delta Reef and Cape Frederick. North-dipping submarine pillow lavas and associated hyaloclastite deposits are capped by flat-lying subaerially-erupted plains-type lava flows.

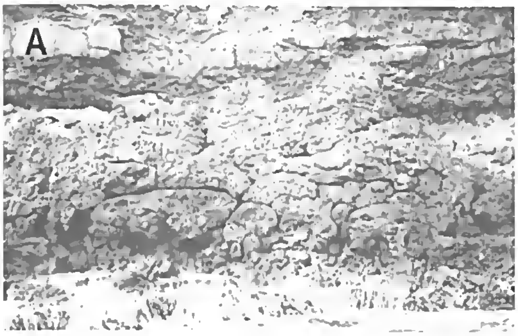

Fig. 6. A: Solid pillow mass at Square Reef. These classically shaped pillows have convex upper surfaces and bases that are moulded to the shapes of underlying pillows. Note the ubiquitous radial jointing. The transition into the overlying flat sheets of subaerial plains-type lava flows occurs at 12m above sea level.

B: View of the western headland of Dinghy Cove. Entwined pillows intimately associated with hyaloclastite. Note radial jointing and the well defined chilled crust in the upper pillow (clearest near hammer pick), and spreading cracks and blocky surface texture of the lower pillow.

Fig. 7. Longitudinal and transfer spreading cracks in a pillow lobe surrounded by hyaloclastite, western headland of Dinghy Cove.

Fig. 8. Congealed lava tongue overlying a lava bench in the hollow tube of a drained pillow lobe, western headland, Dinghy Cove. Note the tiny lava stalactites extending from the irregular surface of the roof above the lava tongue, and the hyaloclastite that completely encloses this particular pillow.

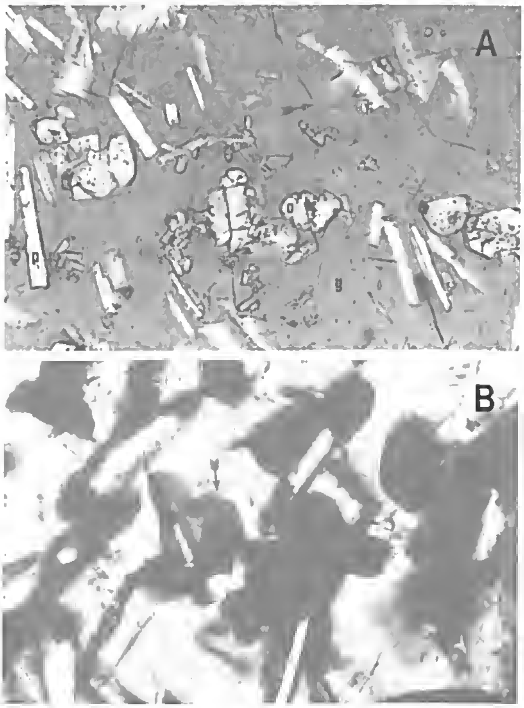

Fig. 9. A: Outer glassy margin of a pillow (Dinghy Cove). The basaltic glass (g) is altered to palagonite and contains well formed crystals of plagioclase (p) and olivine (o). Arrow indicates perlitic fractures. PPL; Field of view 20mm.

B: The spherulitic zone begins with the appearance of opaque crystallites, seen here to form dark spherulitic clusters (arrow) in the basaltic glass. Pale elongate crystals are plagioclase. PPL; Field of view 6.5mm.

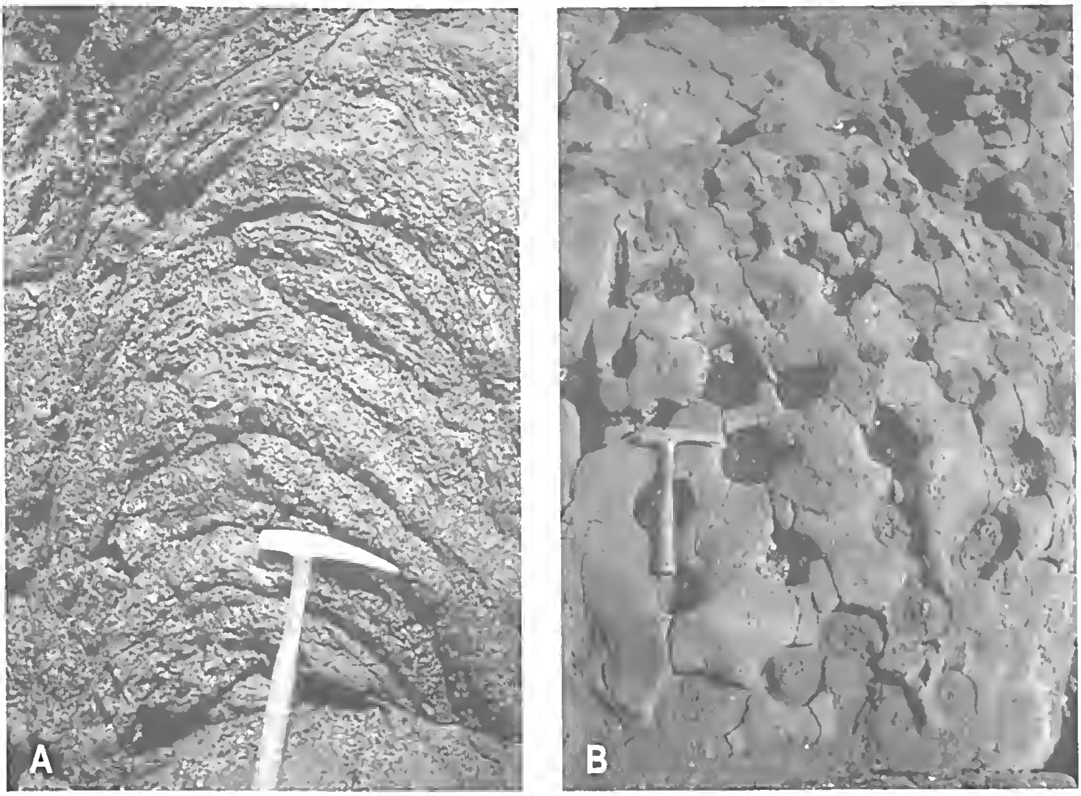

Fig. 10. Some features of the Pahoehoe lava flow, McCoy Platform. A: Ropy lava textures common to Hawaiian-type pahoehoe lavas and; B: Vertical pipe vesicles.

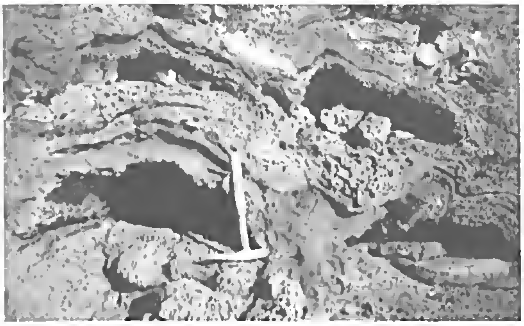

Fig. 11. Internal structure of pahoehoe flow, Thunder Point. Note the distributary tube system within each thin flow. The tube in the lower right corner has a false lava base and secondary carbonate has begun to fill the tube to the top left.

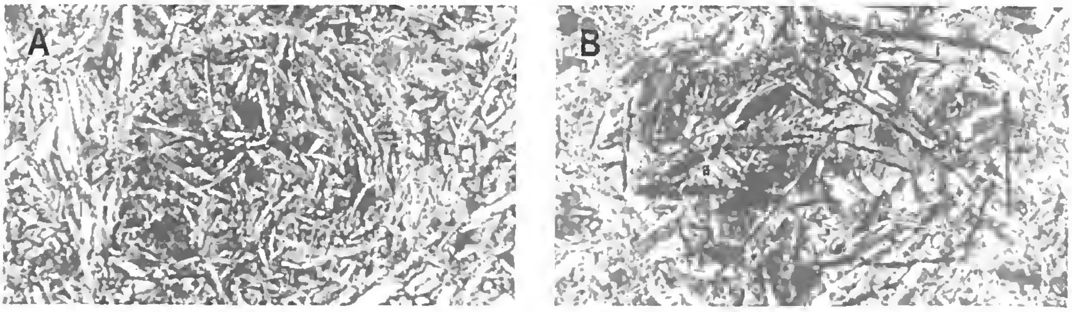

Fig. 12. Globules in the pahoehoe lava. A: Almost spherical globule with a well defined rim of plagioclase and augite crystals. Note the higher concentration of late-crystallising ilmenite within the globule. (Dinghy Cove) PPL; Field of view 40mm. B: Emulsion-like globule with elongated pyroxene (a) and ilmenite (i). Note the coarser grain size of the globule compared to that of the host lava. (McCoy Platform) Cross polars; Field of view 20mm.

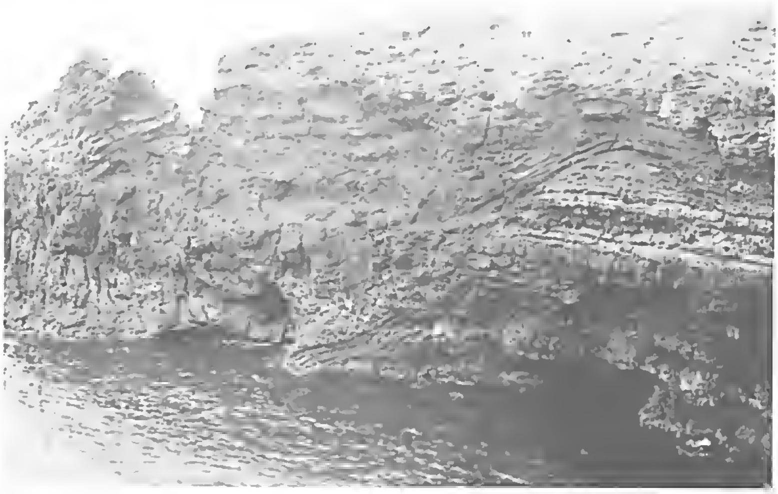

Fig. 13. Volcanic vent at Pinnacle Point, viewed across Horseshoe Bay from Thunder Point. This vent intrudes pillow lavas from earlier submarine volcanic eruptions (bottom-right). The first eruption produced pyroclastic flows (light material middle-right), subsequently truncated by plains-type lava flows seen draped over them at angles of up to 30°. What remains of the throat of the vent is now filled with massive columnar-jointed basalt (bottom-left). The thinly bedded lava and scoriaceous layers (upper-left) at the top of the pinnacle fused to form the elastogenic flows that cap the southern portion of the island.

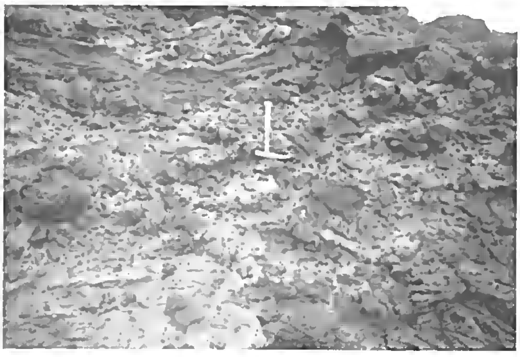

Fig. 14. Pyroclastic flow exposed in cliffs at Thunder Point (see also Fig. 12). The pick lies against the middle section of flow unit. Notice the upward increasing percentage of large basalt blocks. There is a sharp transition to the top section that is thinly bedded and much finer grained.

PRELIMINARY OBSERVATIONS ON THE REPRODUCTION, GROWTH AND DIET OF *UROLOPHUS CRUCIATUS* (LACÉPÉDE) AND *UROLOPHUS EXPANSUS*, McCULLOCH (*UROLOPHIDAE*) IN SOUTHEASTERN AUSTRALIA

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Treloar, M.A. & Laurenson, L.J.B., 2005. Preliminary observations on the reproduction, growth and diet of *Urolophus cruciatus* (Lacépéde) and *Urolophus expansus*, McCulloch (*Urolophidae*) in South-eastern Australia. *Proceedings of the Royal Society of Victoria* 117(2):341–347. ISSN 0035-9211. Corrigenda from 116(2):183–190. ISSN 0035-9211.

This study examines the diet, growth and reproduction of two species of stingarees (*Urolophus cruciatus* and *U. expansus*) that occur off the south-east coast of Australia and are bycatch of commercial trawlers targeting latchet, flathead and jackass morwong. Both stingarees prey on similar species but in different proportions. Dominant prey for both stingarees were primarily crustaceans (isopods) followed by polychaetes. No significant difference was found between sexes though diet varied with size in both species. Sexual maturity for female and male *U. cruciatus* was attained at 320 mm and 315 mm total length, respectively. Male *U. expansus* matured at a total length of 360 mm with insufficient numbers of females to determine sexual maturity.

Keywords: Urolophids, stingarees, von Bertalanffy, prey

THE family Urolophidae (round stingrays and stingarees) contains three genera (*Urolophus*, *Trygonoptera* and *Plesiobatis*) and 40 species, 22 of which occur in Australian waters. Stingarees are found in habitats ranging from shallow to inner-continental waters, estuarine outlets and deep offshore waters to at least 700 meters (Last and Stevens, 1994). Two species of stingarees, *Urolophus cruciatus* and *Urolophus expansus* are commonly caught as bycatch off the southwestern coast of Victoria.

The life history of stingarees in Australia is poorly understood with only few published studies from the west coast of Australia (White, 1998; White et al., 2001) and Port Phillip Bay, Victoria (Edwards, 1980). In this paper we describe the diet, reproductive biology and age estimates of *U. cruciatus* and *U. expansus*

MATERIALS AND METHODS

Sample collection and location

A total of 50 *U. cruciatus* and 93 *U. expansus* were collected from southwestern Victorian waters by commercial vessels targeting *Pterygotrigla polyomata* (latchet), *Neoplatycephalus aurimaculatus* (toothy flathead), *N. richardsoni* (tiger flathead) and *Nemadactylus macropterus* (jackass morwong) between March and June 2001. These specimens were bycatch of commercial otter trawls (40 m foot-line; 90 mm or 110 mm stretch mesh) fished at depths between 198 and 324 m. Trawling was conducted at speeds between 2.8 and 3 knots with sweep lengths of 180 m.

Specimens were identified and blotted dry, weighed (± 1 mm) and total length, TL (± 1 mm), disc width, DW (± 1 mm), mouth length, ML (± 1 mm) and length of tail spine (± 1 mm) recorded according to Last and Stevens (1994).

Stomachs were removed, weighed and fullness assessed using a scale from 1–5 where 1 is empty and 5 is full. Stomachs were stored in 70% ethanol and examined later under a dissecting microscope. Prey items were identified to the lowest possible taxonomic level using Jones and Morgan (1994) and Edgar (2000). Victorian Museum staff assisted when identifications could not be made from available literature. Number of prey species and the number of individual prey items were recorded for each stomach. Diet data was analysed using the Frequency of Occurrence ($F = (\frac{N}{T}) \times 100$) (Hyslop, 1980).

Where N is the number of stomachs containing a particular prey item and T is the total number of stomachs examined.

Analysis of similarities (ANOSIM, PRIMER v5.2.0) (Clarke and Gorley, 2001; Clarke and

Gorley, 2001) was used to determine differences in diet between sex, species and size.

Reproductive development was assessed using the stages of Snelson et al. (1988). Female stages were; (1) immature, (2) developing, (3) mature, non-pregnant, (4) mature, pregnant, and (5) mature, post-partum. Male stages were: (1) immature, (2) maturing, virgin (3) mature, non-reproductive, and (4) mature, sexually active. Clasper length was measured to the nearest mm using callipers and clasper calcification recorded.

Vertebrae were used to obtain preliminary assessments of age. After dissection from specimens, vertebrae were immersed briefly in boiling water and cleaned of remnant connective tissue. Dried vertebrae were embedded in polyester/epoxy resin and 0.3 mm sections cut longitudinally using a diamond saw. Sections were viewed under a compound microscope at ×10 magnification. If band definition was unclear sections were enhanced by emersion in methyl salicylate. Band counts were repeated three times, with 25% of the samples counted by an independent reader. Growth was described using the von Bertalanffy growth model (with t_0 constrained to 0) using Fisat II (Gayanilo and Pauly, 2001). Vertebrae were aged 'blind' and re-analysed twice for standardisation and accuracy with reader precision assessed using the Index of Average Percent Error (Beamish, 1981).

$$\mathrm{IAPE} = \frac{100}{\mathrm{N}} \sum_{j=1}^{N} \left(\frac{1}{R} \sum_{i=1}^{R} \frac{|Xij - Xj|}{Xj} \right)$$

Where

N= number of fish aged

R= the number of age determinations for each fish

X_{ij} = the ith determination for the ith fish

X_j = the average estimated age of the *i*th fish

RESULTS

Dietary composition of U. cruciatus and U. expansus

Prey species found in the stomachs of *U. cruciatus* and *U. expansus* represented six phyla and 15 families (Table 1). Crustaceans dominated the diet of both species, isopods *Natatolana woodjonesi* and *N. wowine* being the most common. Polychaetes had a higher frequency of occurrence in *U. cruciatus* while greater numbers of polychaetes occurred in the diet of *U. expansus*. Adult insects (unidentified due to being partly digested) were found in the stomachs of both species; however these results are considered an anomaly and may have been consumed by the animals while on the sorting tables of trawlers. Twenty-three prey species were present in the stomachs of both *U. cruciatus* and *U. expansus* with eleven being common to both species (Table 1).

Variations of diet between size class, sex and species

Two distinct cluster patterns and two outliers (Fig. 1) were evident in the hierarchical cluster analysis of the diet of *U. expansus* and *U. cruciatus*. The stress factor for the MDS was 0.09 suggesting a low risk of drawing false inferences (Clarke, 1993). No consistent patterns in clustering by sex or species were evident. However, distinct length-based grouping occurred with *U. expansus* differing amongst the 151–200 mm (C), 201–350 mm (A), and 351–500 mm TL (B) size classes and *U. cruciatus* differing amongst the 251–300 mm (A), 301–400 mm (B) and 401–450 mm TL (D) size classes.

Although ANOSIM demonstrated that each size class differed significantly (R=0.555), it also showed that both species were similar with an R-statistic value of 0.143 and a stronger correlation between all males and females (R= -0.012). Further analyses on male and female diet within size classes were combined because of the absence of differences in diet by sex. The R-statistic value for males and females of *U. expansus* had a close relationship of -0.031 while *U. cruciatus* followed a similar trend of R=0.019. A separate ANOSIM test on all males from both species showed a correlation between the two (R=0.105) while an individual test performed on females alone showed no similarities (R=0.648). Although there were no correlations in *U. expansus* size classes, *U. cruciatus* correlated well within its species with an R-statistic value of -0.158.

Age Estimates

A sample of 49 *U. cruciatus* and 87 *U. expansus* sections were examined under the microscope. An intra-reader precision test was performed on all readable vertebrae from both species. IAPE's for *U. cruciatus* and *U. expansus* were 7.51% and 6.02%, respectively, indicating high degrees of repeatability in the estimation of ages. von Bertalanffy growth parameters (Table 2) showed that female *U. expan-*

Phylum	Class/Order	Family	Species	*U. cruciatus*		*U. expansus*	
				%F	%N	%F	%N
Annelida	Polychaeta		Total	52	20.37	26.88	32.95
		Eunicidae	*Sp. 1	8	3.7	6.45	2.73
			*Sp. 2	8	1.65	8.60	1.93
			*Sp. 11	6	0.82	0	0
			*Sp. 23	0	0	3.23	0.64
		Flabelligeridae	*Sp. 10	12	4.73	2.15	4.66
		Pectinariidae	*Sp. 15	24	8.44	2.15	0.64
		Amphinomidae	*Sp. 19	0	0	12.9	22.35
		Scalibregmatidae	*Sp. 36	8	1.03	0	0
Nematoda			*Sp. 7	10	1.44	12.9	3.54
Priapulida			Total	8	1.44	4.30	0.80
		Priapulidae	*Sp. 16	8	1.44	2.15	0.32
			*Sp. 28	0	0	2.15	0.48
Crustacea			Total	80	76.13	73	65.12
	Isopoda		Total	50	54.11	45.16	46.3
		Cirolanidae	*Natatalana waadjanesi*	40	17.9	22.58	11.41
			Natatolana wawine	26	36.21	39.78	34.89
	Amphipoda		Total	42	9.05	21.5	9.65
		Phoxocephalidae	*Sp. 14	26	5.76	16.13	7.88
			Brolgus tattersalli	22	3.29	8.6	1.77
	Decapoda		Total	36	12.97	31.18	9.17
		Pasiphaeidae	*Leptachelia sydniensis* (shrimp)	22	10.91	6.45	2.25
		Erangonidae	*Sp. 32 (shrimp)	12	1.85	17.2	5.47
		Palinuridae	*Jasus sp. (juvenile)*	2	0.21	0	0
		Portunidae	*Sp. 27 (crab)	0	0	2.15	0.32
		Scallaridae	*Scyllarus crenatus* (slipper lobster)	0	0	8.60	1.13
Mollusca	Cephalapoda	Sepiolidae	*Euprymna tasmanica* (dumpling squid)	4	0.41	0	0
Insecta	Unknown	Unknown	*Sp. 38 (winged insect)	1.08	0.16	0	0
			*Sp. 37	0	0	2	0.21

Table 1. Prey items found in *Urolophus cruciatus* and *Urolophus expansus*. Frequency of occurrence (%F) and contribution by numbers (%N) * = Unidentified.

sus grow to a smaller size than males (due to absent mature female specimens the von Bertalanffy growth equation may not accurately represent growth in this species) and *U. cruciatus* females growing to a larger size than males. It should be noted that these age estimates are yet to be validated.

Reproduction

Onset of maturity for male *U. expansus* was at approximately 360 mm TL (Fig. 2a). Of the 79 male *U. expansus* examined, 16 were immature while 63 were mature. Insufficient samples of female *U. expansus* were obtained to allow assessment of onset of maturity.

Male *U. cruciatus* matured at 315 mm TL (Fig. 2b). Five *U. cruciatus* males were immature while 22 were mature. Female *U. cruciatus* matured at 320 mm TL (78% of maximum observed total body length). Seven *U. cruciatus* females were immature and 16 were mature.

Male *U. expansus* and *U. cruciatus* reached sexual maturity at the age of 7 years (360 mm TL) and 6 years (315 mm TL) respectively. Female *U. cruciatus* attained sexual maturity at the age of 6 years at approximately 320 mm TL. Insufficient *U. expansus* females were collected to determine age at sexual maturity.

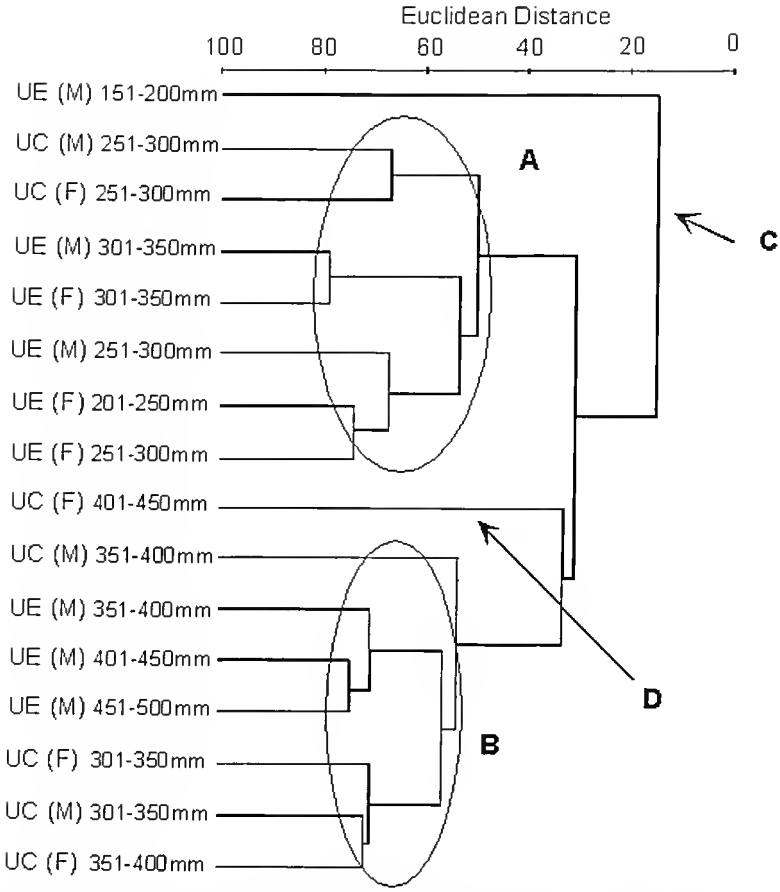

Fig. 1. Dendogram of variations of diet for male (M) and female (F) *Urolophus expansus* (UE) and *Urolophus cruciatus* (UC) size classes (rounded to the nearest 10 mm) caught in south-eastern Australian waters.

Macroscopic Stages of Gonads

Urolophus expansus females were either stage 1 or 2 (immature with no ovarian development or very small ovaries). No specimens larger than 350 mm TL were collected. Over 50% of female *U. cruciatus* had stage 3 gonads, (mature but not pregnant). Two female specimens (378 mm and 335 mm TL) possessed two pups. Male and female pups had a mean total length of 114 mm and 105 mm, respectively and mean weight of 14.5 g and 10.8 g, respectively. One female had dark trophonemata and a flaccid/enlarged uterus suggesting it had recently given birth.

Most *U. expansus* males had stage 3 gonads (mature but non-reproductive) or stage 4 gonads (mature and sexually active). Males up to 310–350 mm TL were either stage one or stage two (still maturing). *U. cruciatus* males matured earlier than *U. expansus* males as all animals were a stage 3 or 4 in the 310–350 mm TL size range.

DISCUSSION

Dietary Analysis

Urolophus cruciatus and *U. expansus* fed mostly on benthic organisms inhabiting sand and reef topography. The presence of coral, sponge and grit in their stomachs, combined with their mouth structure and morphology, suggests that these two stingarees are non-selective benthic feeders.

Crustaceans were the dominant prey in both species with isopods being the principle prey. Isopods can be parasitic or carnivorous (Hale, 1927–1929) with *Natatolana* species occurring in a range

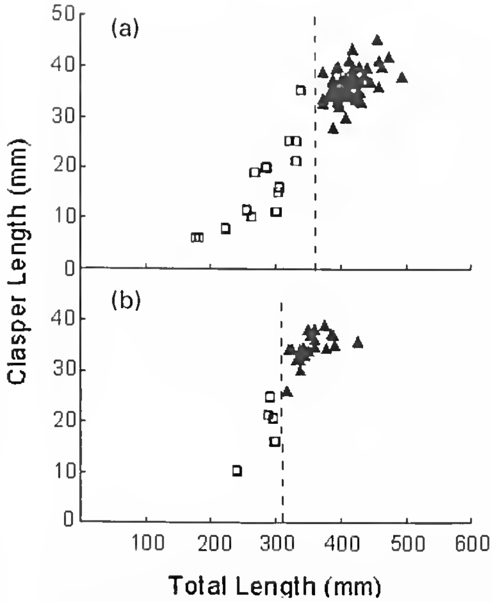

Fig. 2. Relationship between clasper length (mm) and total length (mm) for male a) *Urolophus expansus* (n=79) and b) *Urolophus cruciatus* (n=27) showing onset of maturity (represented by the dashed line) by clasper calcification and uncalcified caught from south-eastern Australian waters.

of sediments into which it burrows (Johansen and Brattegard, 1998), therefore it is easily preyed upon by bottom feeders. Most isopods examined were crushed and semi-digested indicating that they were presumably prey. Nematodes were found undigested in many stingaree stomachs. While there are many parasitic species in Australian temperate waters; most marine representatives live freely among the sediment and seaweed (Edgar 2000). These nematodes found were believed to be parasitic, as they were also present whole in the intestinal portion of the alimentary tract.

The presence of small numbers of benthic prey in the diet of *U. cruciatus* such as the dumpling squid (Family *Sepiolidae*) which buries itself into the sand (Norman and Reed 2000), sedentary polychaetes and amphipods suggests that *U. cruciatus* forages deeper into the sediment after prey. In contrast, *U. expansus* feeds more from the top sediments on epibenthic organisms including slipper lobsters (*Scyllarus crenatus*), crabs and more errant polychaetes that do not burrow as deeply into the sediments. ANOSIM showed extensive overlap in diet between *U. cruciatus* and *U. expansus*, despite only 11 of the 23 prey categories being common to both species.

There was no difference in diet between male and female of either species suggesting that there are no sexually based variations in foraging behaviour.

Urolophus expansus exhibited a great variation in diet with size, and fed on a range of prey species. Individuals from both species measuring between 150–300 mm TL preyed on small isopods, carid decapods and large numbers of amphipods (in different proportions). With increasing size, both species consumed a larger variety of prey with bigger isopods and amphipods ingested as well as prawns, slipper lobsters, priapulids and larger numbers of polychaetes. Isopods occurred frequently in the stomachs of all sizes of both species and the size of ingested isopods was positively correlated with stingaree size. Various studies (Andrews, 1988; Kohler and Fitzgerald, 1969; Platell et al., 1998) have shown that prey species are directly related to predator size. Platell et al. (1998) investigated the diet of *U. lobatus* and *U. paucimaculatus* off the south western coast of Australia in depths less than 35 m. It was found that *U. lobatus* and *U. paucimaculatus* initially fed mostly on amphipods, mysids and carid decapods. With increasing size, *U. lobatus* ingested teleosts and *U. paucimaculatus* preyed on polychaetes and penaeid decapods. Mysids were not found in the diets of *U. cruciatus* and *U. expansus*.

Species	Sex	L°	k
Urolophus expansus	Female	46.95±34.6	0.21±0.44
	Male	59.56±4.29	0.14±0.03
Urolophus cruciatus	Female	50.95±4.26	0.18±0.03
	Male	46.31±4.17	0.21±0.05

Table 2. von Bertalanffy parameter estimates (± 1 standard error) for male and female *Urolophus cruciatus* and *Urolophus expansus* collected from south-western Victoria. Data fitted using Fisat II (Gayanilo and Pauly 2001) with t_0 constrained to 0.

which may be due to unavailability or selective feeding behaviours. Teleosts were not present in the diet of either species. Studies on *U. lobatus*, *U. paucimaculatus* and *Trygonoptera mucosa* in Australian waters also found that these species consumed teleosts in their adult stages (1998).

Our data suggests that *U. expansus* and *U. cruciatus* utilise similar habitats consuming 11 of the same organisms but in different proportions. The reason why only 11 of the specimens preyed upon were similar could be due to their different foraging techniques and mouth structure as discussed earlier.

REPRODUCTION

Size at Sexual Maturity

Based on clasper size and calcification, male *U. expansus* and *U. cruciatus* matured at 360 mm and 315 mm TL, respectively. Last and Stevens (1994) recorded the smallest mature *U. expansus* and *U. cruciatus* males to be 410 mm and 250 mm TL, respectively. Variations with Last and Stevens (1994) may be due to different sample sizes and population differences. With a larger sample size the estimated onset of maturity may be earlier than stated.

Urolophus cruciatus females matured at 320 mm TL. Only immature female *U. expansus* were examined and so length at maturity could not be determined.

From preliminary age estimates, the youngest pregnant female and mature male *U. cruciatus* were 6+ years. The youngest mature *U. expansus* male was 7+ years.

Gestation Period

Urolophids are viviparous (trophonemata) giving birth to live young (Campbell, 1996). Gestation period was difficult to determine in both species because of the lack of mature, pregnant and post-partum animals. Female pups from *U. cruciatus* measured 103 mm TL and 107 mm TL with males having a total length of 111 mm and 117 mm. The birth size is unknown for these species though it is presumed that these pups were close to being released as they were well developed. The brown stingaree (*Urolophus westraliensis*) and Coral Sea stingaree (*Urolophus* sp. B) pups are born at total lengths of 100 mm (Last and Stevens 1994). Both U. westraliensis and U. sp. B (Last and Stevens 1994) are tropical stingarees with males maturing at 240 mm and 230 mm TL respectively, a smaller size than *U. cruciatus* and *U. expansus*, suggesting a smaller length at birth.

As a generalization, stingarees have litters of 2–4 pups that take about 3 months to gestate (Last and Stevens, 1994), although White et al. (2001) found that *U. lobatus* in western Australia took 10 months to gestate. Since *U. cruciatus* and *U. expansus* are also found in Australian waters gestation could also be longer than 3 months. If gestation is longer than 3 months and litters are only 2–4 (a low fecundity) with survival rates unknown productivity of these species could be extremely low and commercial exploitation very dangerous.

Age and Growth

Elasmobranchs cannot at present be aged using traditional fish ageing methods, since they lack the necessary calcified structures i.e otoliths and scales. Consequently spines and vertebral centra are commonly used for age and growth studies (Cailliet et al., 1986; McEachran et al., 1976). Validation was not carried out in this study due to small sample sizes. For the preliminary data required in this study it is presumed that growth bands were deposited annually, similar to other ageing studies of stingarees (White et al., 2001).

CONCLUSIONS

It was found that *U. cruciatus* and *U. expansus* are non-selective benthic feeders. Both species feed predominantly on the same organisms with isopods being the major prey item. No differences were found in the diet between males and females of the same species; however it was shown that diet composition and make-up varied with size. Diet variation occurred between the different size classes with smaller animals consuming smaller and fewer prey items. A greater variety of prey items became important in larger individuals.

This study has shown that *U. expansus* males mature at 7 years (36 cm TL, 24.7 cm DW) while female maturity could not be determined due to insufficient data. Both *U. cruciatus* sexes mature at 6 years though females mature at 31.5 cm TL and males at 32 cm TL. Disc width at maturity was 21.3 cm for both sexes.

ACKNOWLEDGEMENTS

We would like to express our thanks to Deakin University for their support and the use of their facilities. The assistance of Graeme Cottier, Crisbian Ashby and fishermen for the collection of specimens were much appreciated. A big thanks to Simon Robertson from MaFRI, PhD student Sarah Irvine, Peter Last (CSIRO), William White (student from Murdoch) and to staff from Victorian Museum Martin Gomon, Gary Poore and Robin Wilson.

REFERENCES

Andrews, J. S. (1988). The feeding ecology of sand flathead (*Platycephalus bassensis*, Cuvier) from Port Phillip Bay, Victoria. Science. Melbourne, Victoria, La Trobe University.

Beamish, R. J. and Fournier, D.A. (1981). "A Method of Comparing the Precision of a set of age Determinations." *Journal of the Fisheries Research Board of Canada* 36: 735–743.

Cailliet, G. M., Radtke, R. L. and Welden, B. A. (1986). *Elasmobranch Age Determination and Verification:* A Review. Indo-Pacific Fish Biology: Proceedings of the Second International Conference on Indo-Pacific Fishes., Tokyo, Japan.

Campbell, N. A. (1996). *Biology: Fourth Edition.*

Clarke, K. R. (1993). "Non-parametric multivariate analyses of changes in community structure." *Australian Journal of Ecology* 18: 117–143.

Clarke, K. R. and Gorley, R. N. (2001). Change in marine communities: an approach to statistical analysis and interpretation. Plymouth, Primer-E Ltd.

Clarke, K. R. and Gorley, R. N. (2001). Primer v5: User manual/tutorial. Plymouth, Primer-E Ltd.

Edgar, G. J. (2000). *Australian Marine Life the plants and animals of temperate waters.* Sydney, Australia, Reed New Holland.

Edwards, R. R. C. (1980). "Aspects of the Population Dynamics and Ecology of the White Spotted Stingaree, *Urolophus paucimaculatus* Dixon, in Port Phillip Bay, Victoria." Aust. J. Mar. *Freshwater Research*. 31: 459–67.

Gayanilo, F. C. J. and Pauly, D. (2001). FiSAT II. Rome, Food and Agriculture Organisation of the United Nations.

Hale, H. M. (1927–1929). *The Crustaceans of South Australia.* South Australia, A. B. James Government printer.

Hyslop, E. J. (1980). "Stomach Contents analysis-a review of methods and their application." *J. Fish. Biol* (17): 411–429.

Johansen, P. O. and Brattegard, T. (1998). "Observations on behaviour and distribution of Natatolana borealis." Sarsia 83(4): 347–360.

Jones, D. and Morgan, G. (1994). A Field Guide to Crustaceans of Australian Waters, Reed Publishers.

Kohler, A. C. and Fitzgerald, D. N. (1969). "Comparisons of food of cod and haddock in the Gulf of St. Lawrence and on the Nova Scotia Banks." *Journal of Fisheries Research Board of Canada* 26: 1273–1287.

Last, P. R. and Stevens, J. D. (1994). *Sharks and Rays of Australia*. Hobart, CSIRO.

McEachran, J. D., Boesch, D. F. and Musick, J. A. (1976). "Food Division within Two Sympatric Species-Pairs of Skates (Pisces: Rajidae)." *Marine Biology* (35): 301–317.

Platell, M. E., Potter, I. C. and Clarke, K. R. (1998). "Resource Partitioning by four species of elasmobranchs (Batoidea: Urolophidae) in coastal waters of temperate Australia." *Marine Biology* (131): 719–734.

Snelson, F. F., Williams-Hooper, S. E. and Schmid, T. H. (1988). "Reproduction and Ecology of the Atlantic Stingray, *Dasyatis sabina*, in Florida Coastal Lagoons." Copeia 3: 729–739.

White, W. (1998). The Age Compositions, Growth Rates and Reproductive Biology of Four Species of Elasmobranchs (Batoidea: Urolophidae) in Coastal Waters of South-Western Australia, Murdoch University. THESIS

White, W. T., Platell, M. E. and Potter, I. C. (2001). "Relationship between reproductive biology and age composition and growth in *Urolophus lobatus* (Batoidea: Urolophidae)." *Marine Biology* (138): 135–147.

TRANSACTIONS

OF THE

ROYAL SOCIETY OF VICTORIA

Volume 117

NUMBER 2

EXPLANATORY NOTES

Some additional corrigenda from Volume 116 are also included here:

PETER N. JOUBERT
Some remarks on the Sydney–Hobart race
This paper from Vol. 116 Transactions is reprinted in full, including figures

MARK WARNE
Supplementary notes on the subgenus *Loxocythere (Novoloxocythere)* Warne and some comparable ostracod taxa

Corrigenda for the following two papers from Vol. 116 Proceedings are included with additional unreferee-ed notes

Warne, M.T., 2004a. Description of *Loxocythere (Novoloxocythere) pelius* subgen. *et* sp. nov. (Ostracoda) from the Cenozoic of S.E. Australia with comments on species of *Antarctiloxoconcha* Hartmann, 1986 and *Loxoreticulatum* Benson, 1964 from Australian and Antarctic marine waters. *Proceedings of the Royal Society of Victoria* 116(2): 233–241.

Warne, M.T., 2004b. Observations on *Loxocythere (Loxocythere) onyenensis* (Chapman, 1914) (Ostracoda) from the Cenozoic of S.E. Australia with comments on species attributed to *Microcytherura* Müller, 1894 and *Hemiparvocythere* Hartmann, 1982 from Australian and New Zealand marine waters. *Proceedings of the Royal Society of Victoria* 116(2): 243–250.

SOME REMARKS ON THE 1998 SYDNEY–HOBART RACE

PETER N. JOUBERT OAM

[Reprinted from last issue of PRSV]

INTRODUCTION

The 1998 Sydney-Hobart race was sailed in the worst weather on record, a number of yachts were overturned, some were lost, six people lost their lives and there were some amazing heroic efforts by rescuing helicopter crews.

These remarks are mainly about the winds and waves, which were unique.

The race is sailed from Sydney on the east Australia coast, southwards to a turning point off the island on the south-east corner of Tasmania and thence to the port of Hobart (fig1). It is a great race with a great tradition standing equal with both the Fastnet race, run by the Royal Ocean Racing Club of England, and the Newport-to-Bermuda race run by the Cruising Club of America.

Because of natural circulations in the large oceans, there is a southbound current flowing down the eastern Australian coast. Its penetration southwards varies, as does its speed of flow. On the occasion of the 1998 race it was flowing as strongly as I had ever seen it. It was flowing at 4 to 5 knots in a broad stream almost into the coast and it was still flowing strongly south of Gabo Island, which is the last point on the east coast before the yachts cross Bass Strait. It is most likely it had an effect on the steepness of the waves generated by the low pressure system.

That the current was so fast is confirmed by the presence of almost the entire fleet to the east of Gabo Island as reported at the 2.00 pm radio schedule 7th December which is 25 hours after the start and a distance of 230 nautical miles from Sydney.

Bass Strait is about 200 nautical miles wide at its eastern end but narrows to about 120 miles near its centre. It is shallow, under 100 fathoms down to 30 fathoms over much of the region, and notorious for the generation of low barometric pressure systems and accompanying steep waves with the strong winds. It is also a tidal basin with significant tidal flows.

The race started on Boxing Day, 26th December, in a fresh north-easterly breeze and the fleet sailed south with spinnakers flying. At the 2.00 pm radio schedule on 27th December, the weather report was read and a 45 to 55 knot storm warning was issued. During the schedule, when every yacht is contacted and reports its latitude and longitude, any further communication is discouraged. One yacht, Sword of Orion, broke the pattern of response and reported that they were experiencing winds of over 70 knots.

Larger yachts ahead of Sword of Orion had also experienced these hurricane force winds earlier but had not reported them under the rules of yacht racing concerned with outside information.

THE WEATHER

The Australian Bureau of Meteorology were the advisers to the race organizers and the competitors. At a briefing on the 24th December they were unsure how the weather pattern might develop but indicated that weather conditions might become hazardous.

A gale warning was issued before the start of the race on December 26th at 9.00 am.

One hour after the race had started this was upgraded to a storm warning with winds of 45 to 55 knots predicted for the afternoon of the 27th December in Bass Strait.

Since the event, the Bureau has strongly contended that within this forecast of mean speeds is an expectation of gusts to 70 knots (ref. 1). However, there were not many competitors who appreciated this point as, to my knowledge, it had not been mentioned at the oral briefings.

A gust is defined as lasting less than 10 minutes. Of course, to obtain a mean of 50 knots with gusts to 70 knots there would have to be an equal time with gusts of only 30 knots, or its equivalent. This was not observed on Kingurra. What was observed

Peter Joubert has competed in 27 Sydney-Hobart races, being skipper on 24 occasions. He designed all the yachts in which he has competed. Kingurra designed in 1972, is a timber yacht 43 feet LOA, of 13 Tons displacement and has competed in 13 Sydney-Hobart races. The yacht was dumped almost upside down by a giant wave at about 7.00 pm on 27th December but returned upright within about ten seconds. One crew member was lost overboard, to be safely rescued sometime later by a Victorian Police helicopter.

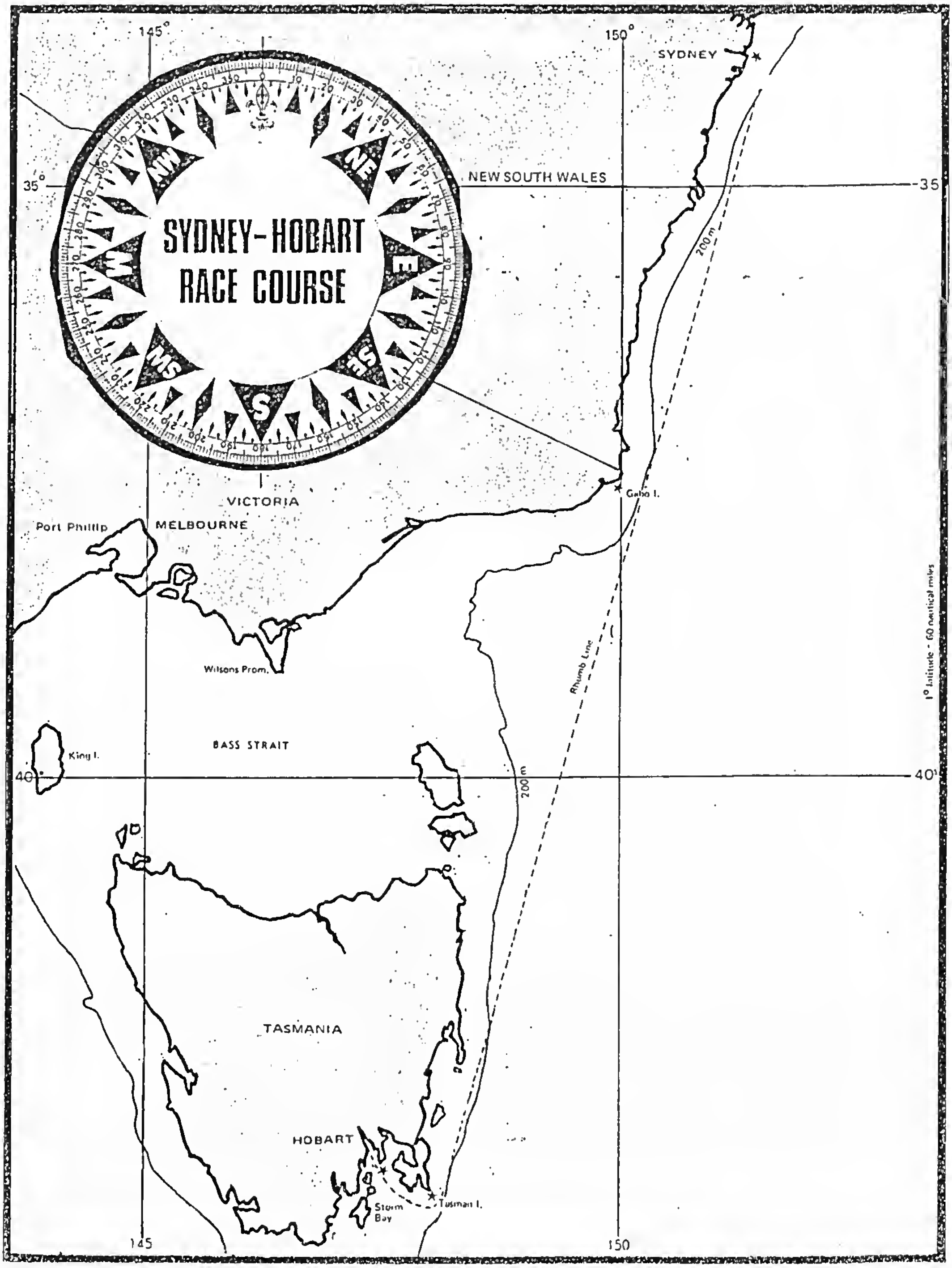

Fig. 1. Sydney–Hobart raee eourse.

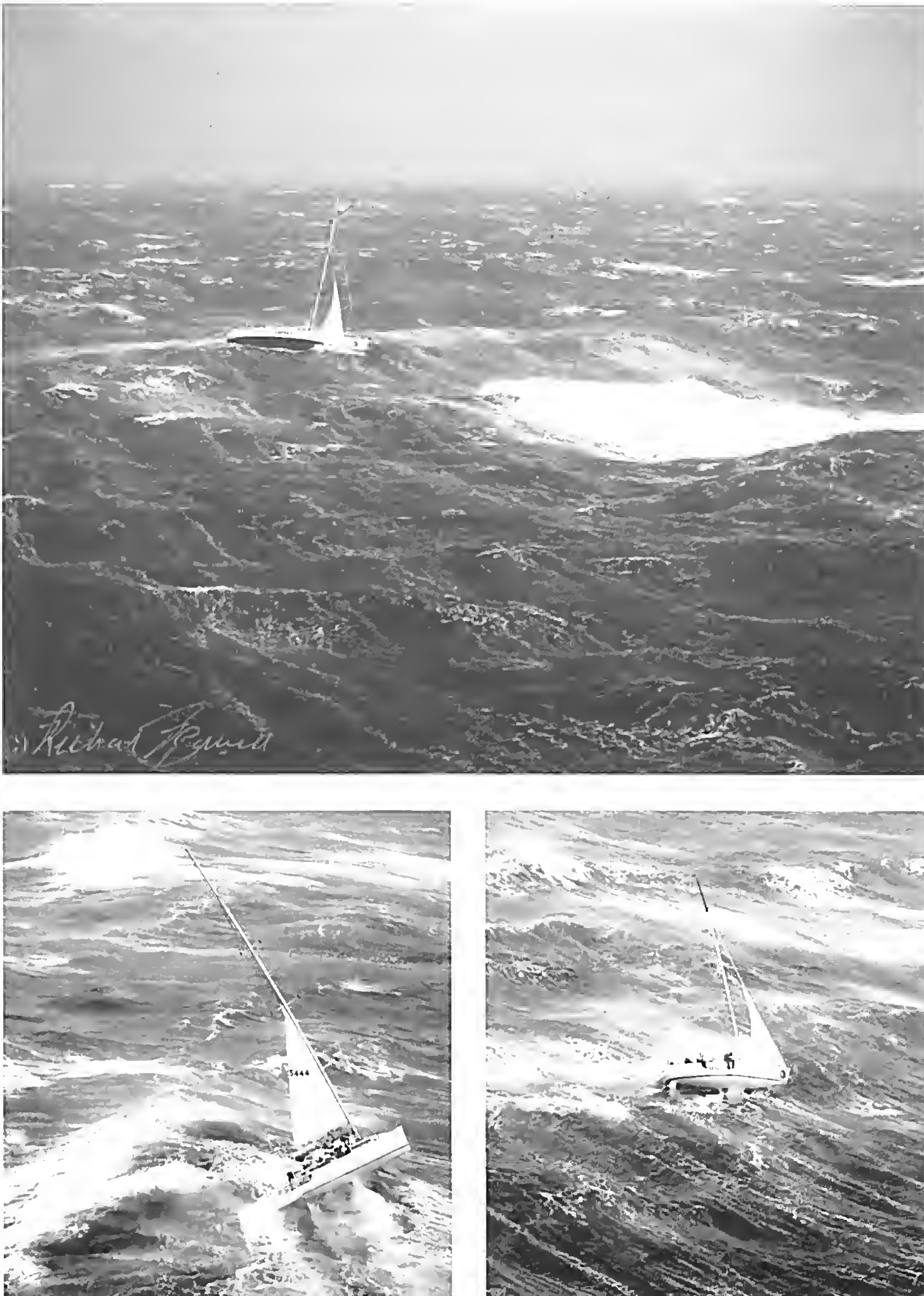

Fig. 2. Yachts heeled to greater than 30° (Photos courtesy Richard Bennett).

Fig. 3. Wave estimated at 80 feet. Abandoned yacht Stand Aside and rescuing helicopter (Bennett photo).

on Kingurra from 3.00 pm to the time when the yachts was dumped by a giant wave at about 7.00 pm, were wind speeds greater than 60 knots. There were only a few short periods when the speed gave a reading below the instrument maximum of 68 knots. Judging by the note of the wind, there were many periods when it was much greater than 68 knots, but how great I cannot say.

In the report of the review committee of the Cruising Yacht Club of Australia (ref. 2) into the 1998 Sydney-Hobart race, on page 45, lines 1–4, it is stated, "most yachts will have recorded apparent wind speeds on board up to about 8 knots faster than the true wind speed due to the effect of the speed of the yacht. Thus average observed wind speeds would have been 60–62 knots with gusts in the low 70 knot range".

What has been neglected in this correction to the wind speed is the effect of heeling of the yacht on a masthead mounted cup anemometer. The speed registered will decrease from the true speed as the cosine of the angle of the heel to the true wind direction. So for a 30° angle of heel, measured in the plane of the true wind, the anemometer would under-read by 13%. Thus the average observed wind speed for a heeled yacht sailing across the wind at 8 knots would have been 69 to 71 knots with gusts over 80 knots. If the boat speed is less than 8 knots, then the true wind speed is greater (see fig 2).

If the yacht's path is angled at other than 90° to the true wind speed then the additive effect of heeling is less and so on through all the complications of relative motions.

Suffice to say that the correction suggested in the CYCA report is simplistic and neglects other more important corrections of the opposite sign.

The light house at Wilson's Promontory reported a wind reading at 6.00 am on 27th December of 71

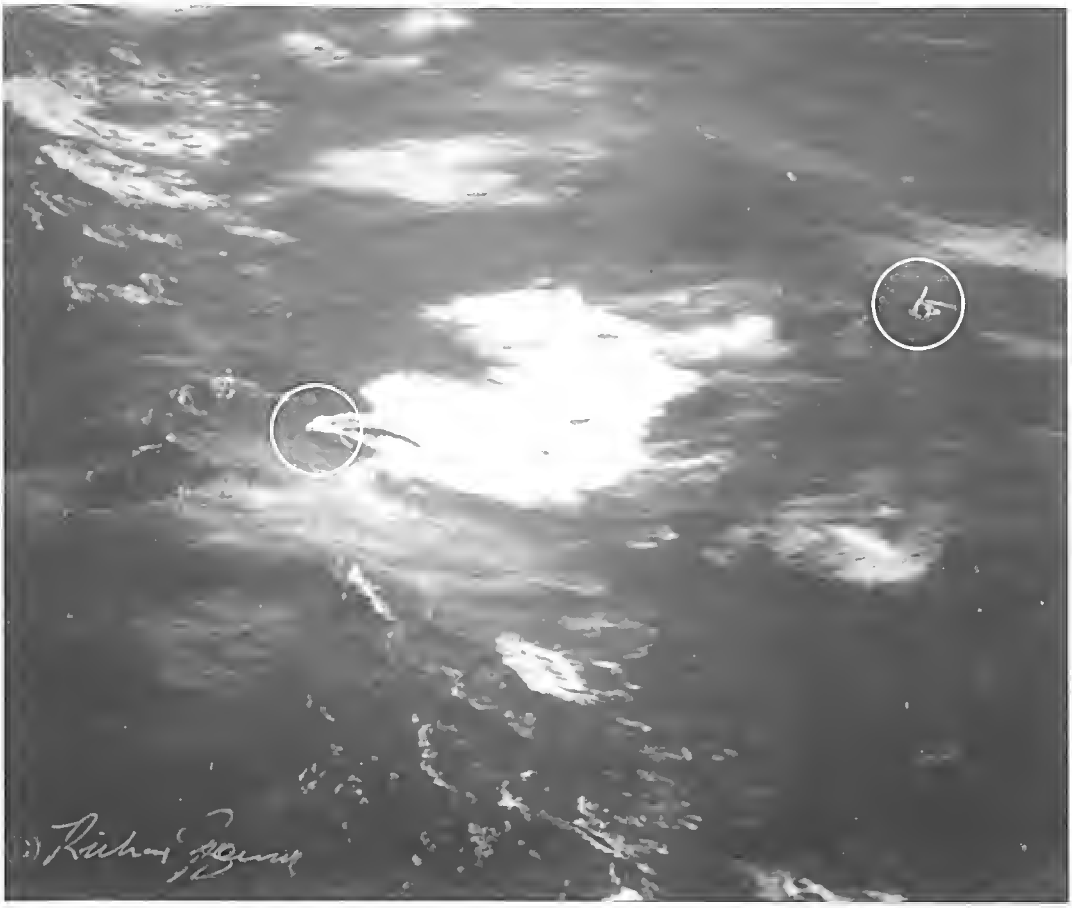

Fig. 4. Stand Aside surfing at high speed on large wave and departing helicopter (Bennett photo).

knots and at 9.00 am of 79 knots. These readings are ten minute averages and the maximum gust recorded was 92 knots. Higher wind recordings from Wilson's Promontory relative to those at other near locations are often observed due to the local topography. In this instance the readings at Wilson's Promontory were not reported to the yachting fleet. The Coroner remarked (p. 104) that, "this was the highest recording of wind speed at Wilson's Promontory for the month of December since accurate wind recordings were commenced in 1998" and on p.127 he found, "that the wind strength at Wilson's Promontory should have been conveyed to the Race Fleet as soon as it was known".

Better evidence on wind speeds is forthcoming from the pilot of the Victorian Police Rescue helicopter which was involved in the rescue of the crew man lost overboard from Kingurra. The pilot of the helicopter, Senior Constable Darryl Jones, presented sworn evidence to the Coronial inquiry on the deaths in the 1998 Sydney-Hobart race (ref. 3). He states that between 4.00 pm and 6.00 pm on 27th December, while flying to the east over the Victorian mainland, he encountered tail winds of 85 knots.

After refuelling at Mallacoota he was directed by ground control to the yacht Kingurra who had reported a man overboard. Kingurra at 2pm was in a position 38°07'S 150°46'E about 45 nm SE of Gabo Island, which is the most southerly point on the east coast and therefore receiving the full force of the winds and the waves moving through Bass Strait.

He states "we arrived overhead at this position in approximately 15–20 minutes where the conditions could only be described as incredible. I have never seen the sea in such a wild and horrendous state. There were rain showers and continuous sea spray and the cloud base ranged from 600 to 2000 feet. We were faced with waves and swells between 80–90 feet in height (see figs 3 and 4) and the occasional

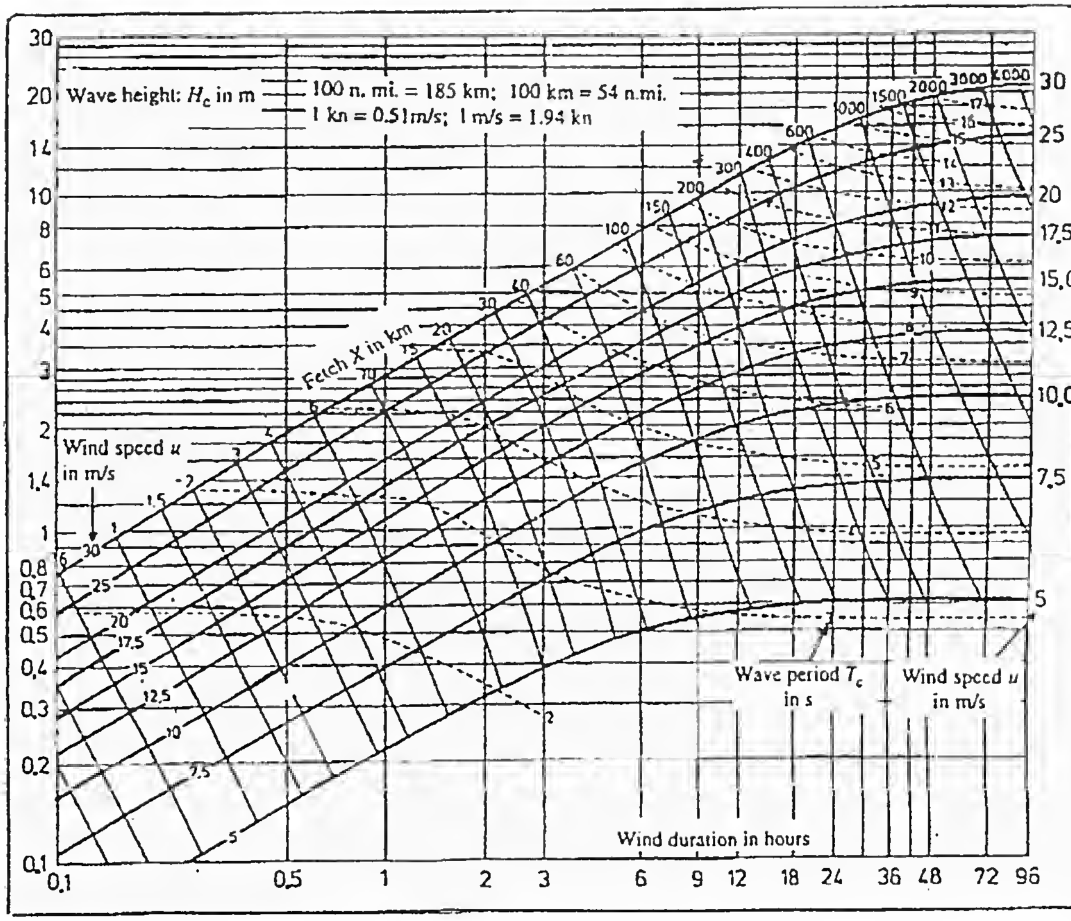

Fig. 5. Manual wave forecasting diagram (from ref. 4).

wave up to 120 feet. The winds were ranging between 70 to 80 knots...."

So the more precise reading of Senior Constable Jones in his helicopter as he hovered is in good agreement with the value found from the CYC report on wind speeds when corrected for angle of heel as done previously, namely 68–70 knots.

This suggests that the forecast value of 45–55 knots from the Weather Bureau is less likely to be a proper measure of the wind speed.

It should be noted that the force of the wind on masts, hulls, sails, crew members and waves is proportional to the square of the velocity. Hence the wind force predicted from the Weather Bureau is half that due to a wind of 70 knots.

It should also be noted that the reading of wind speed by the helicopter was observed when it was at low altitudes so any possible effect of wind variation with height above the seas would not apply.

WAVE HEIGHTS

There is a significant difference between the wave heights as predicted and as measured by the helicopter.

Normal wave theory predicts wave heights which depend on variables such as fetch, wind speed and the time the wind has been blowing. An extract from the Guide to Wave Analysis and Forecasting (ref. 4) is shown as figure 5 where the above three independent quantities are the variables in the predicted heights of the waves.

Due to inequalities, not all waves generated are of the same size nor travelling at the same speed or direction and thus can produce a rearrangement with all the energy going into one wave which is larger and will reach the Stokes peak and break. Currents flowing against the direction of the waves can increase their size significantly. As well there may be

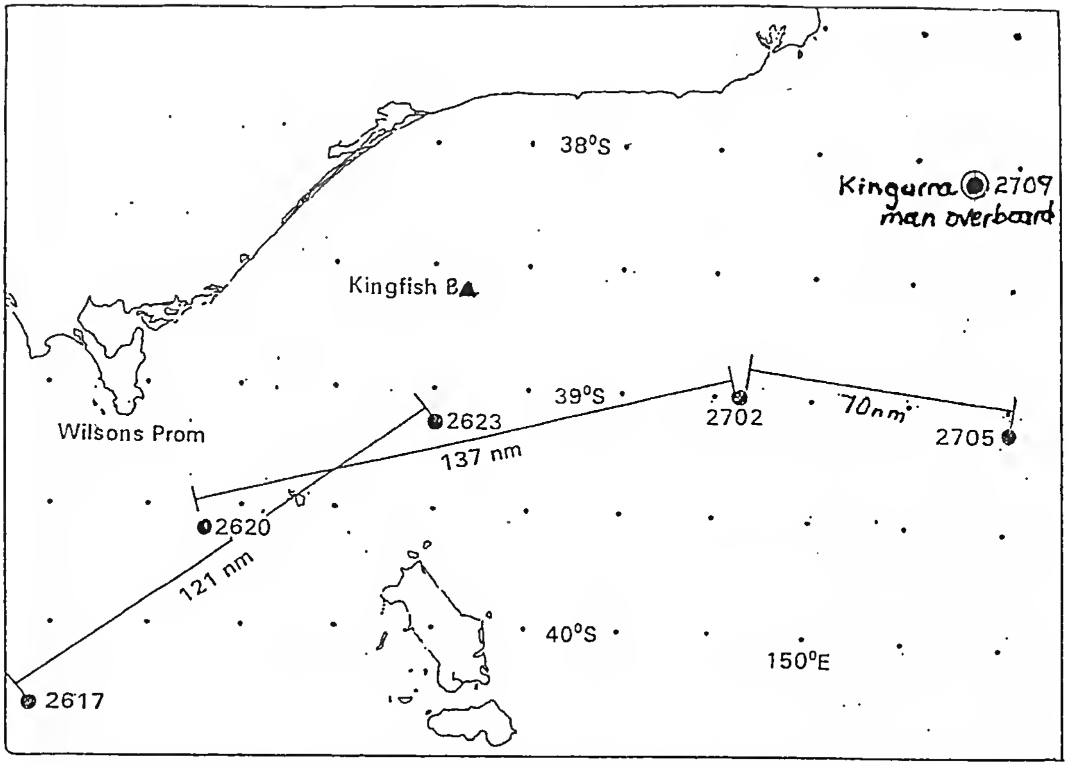

Fig. 6. Positions of the Sydney–Hobart Storm (denoted by large filled eireles) from 1700 UTS 26th Deeember 1998 (2617) to 0500 UTC 27th Deeember 1998 (2705) (eopied from referenee 9). Also shown is the position of Kingurra at the time of man overboard.

swells approaching from a variety of directions as a result of distant storms. Passing crests are additive and add to the extremes.

Predieted wave heights of 4 to 7 metres were generally foreeast in the Bureau's storm warning while infrequent maximum waves with heights to 13 metres could be expeeted. Of eourse, this is a pre-dietion based on the mean winds in the storm being only 45–55 knots. If the mean wind speed was greater then obviously this standard theory will pre-dict greater wave heights.

The Polair helicopter flown by Senior Constable Jones earried a radio altimeter whose function is to measure the height of the helicopter above the ground (or sea) in elose proximity. I have to hand a copy of the speeifieation whieh ineludes a elaimed aeeuraey of ± 2 feet for heights greater than 40 feet. It would be one of the most aeeurate deviees avail-able for measuring wave heights.

Senior Constable Jones had 12 years experienee in the Vietorian Poliee air wing and has flown on a number of hazardous missions. He is a highly

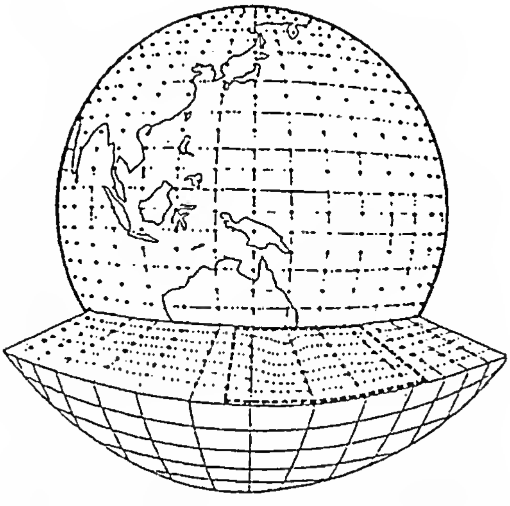

Fig. 7. Sehematie diagram of eourse global grid struc-ture for eomputer modelling (eopied from referenee 11).

trained and skilled pilot and there is absolutely no reason to doubt his observations.

In his sworn statement to the Coronial Inquiry, at the point in his evidence where they had located the lost overboard crewman from Kingurra, John Campbell and the rescuing policeman, Senior Constable Key, was in the water near Campbell, Senior Constable Jones continues, "Key was winched into the water whilst I held a 100 foot hover above the man. Hovering was extremely difficult as I had no reference by which to hold the helicopter in position and Senior Constable Barclay (the crewman observer and winch controller) was constantly talking me into position. Senior Constable Barclay advised me that he would have to pay out a large amount of winch cable due to the size of the swell. Whilst hovering I observed a wall of water coming towards us and confirmed with him that there was plenty of cable out because I had to make an urgent climb to avoid being hit by this wave. He advised me to 'go ahead' and I climbed another 50 feet. This wave passed under the helicopter by approximately 10 feet. I am able to state this because the helicopter is fitted with a radio altimeter which displays the height of the ground or water and I noticed that it reduced to 10 feet as I climbed".

Thus the height of this particular wave was 140 feet (42.7m) which is the largest ever recorded.

One of the highest waves to be measured previously, occurred in Hurricane 'Luis' and was reported by the Master, Captain R.W. Warwick and nine of the officers of the watch of Queen Elizabeth II. The height of the wave was 29 metres and was confirmed later by a nearby Canadian weather buoy which recorded one wave at 30 metres. The report of the event was published by the Meteorological Office in 1996 (ref. 5).

An even larger wave of 34.1 metres was measured by a qualified observer aboard the USS Ramapo in a typhoon in 1933. The measurement was by triangulation and doubters have re-examined the mathematics of that incident ever since.

A letter published in the Seahorse Magazine, October 1999, about aspects of the Sydney-Hobart race by Mr. Kalaugher (ref. 6), suggested that "one wave from a photo had been estimated to be 110 feet high." This produced a comment from an experienced person, Mr. John De Bruin, who stated in his response published in Seahorse Magazine, July 2000, page 28 (ref. 7), as follows: "One remark of Mr. Kalaugher's that I do want to question, however, is that 110 foot wave. I have quite a reasonable amount of offshore experience gained in both the Atlantic and Southern Oceans. Wave height is exponential to strike length and the strength of counter currents. The 1998 Hobart depression encountered a south-going current. Yet the time (of building up) and speed of this depression make it hard to believe 110 foot waves could have developed".

Mr. De Bruin continues with his comments and states "in the Southern Ocean, waves of over 60 feet are considered exceptional, even over the flats to the South of Cape Horn.

In the North Atlantic (my playground) waves of 60 feet or more are rare and are most usually linked to former tropical storms..."

So here lies the heart of the dichotomy of opinion. On the one hand, we have a measurement by a calibrated instrument in the centre of the storm and on the other, disbelief by sailors where the measurement disagrees with accepted theories and their own experience.

Support for the measurement comes from the work of Dysthe and Harbitz (ref. 8) who introduced a simple theoretical model to analyse how a polar low can produce a severe sea condition. When the centre of the low moves with a velocity V having a relationship to the component of wind velocity in the direction of motion U, then a phenomenon known as group velocity quasi-resonance exists. There is then a spectral component in the wave field near the velocity of the storm which will stay in the enhanced wind field of the storm for some time. The phenomenon is also known as fetch enhancement.

In particular:

I. when $V/U<0.25$, the storm motion is too slow to give quasi resonance (fetch enhancement) for the wind field under examination.

II. when $0.25<V/U<0.5$, extended development of waves is possible.

III. when $V/U>0.5$, the polar low will mostly outrun the spectral development at an early stage.

Mr. Jeff Callaghan of the Bureau of Meteorology presented a paper on the development of freak waves near intense lows and tropical cyclones at a conference in December 1999 (ref. 9). I am indebted to him for drawing my attention to the phenomenon of quasi resonance and for allowing me to reproduce part of his paper.

The low in Bass Strait was moving at about 20 knots and its track is shown in figure 6. So conditions were in agreement for quasi-resonance with wind velocities of 70 to 80 knots giving $V/U = 20/75$

= 0.27. The portion of the yacht fleet that experienced the cyclonic winds of 70 to 80 knots from 1400 EDST on December 27th, were in the precise position to be beset by waves that had suffered fetch enhancement over a shallow sea for over nine hours beyond Wilson's Promontory.

The paper by Greenslade describing a subsequent wave modelling study of the events (ref. 10) draws attention to the large eleven second period swell running to the south west as a result of a low pressure system in the Tasman Sea. He remarks (p.56) that this storm had a significant effect on the sea state near the coast. He further suggests that the change in direction of the east Australian current to the east near Gabo Island would increase the size of these waves as well as shortening their period.

WEATHER PREDICTION

The associated major contradiction involves the weather report and the actual measurements of wind velocity. How is it that the wind velocity measured close to the top of the waves by the hovering helicopter was 70 to 80 knots and the weather forecast prediction was 45–55 knots?

The answer may well be given by the manner in which the weather is predicted and the relatively small size of the storm.

Weather is predicted by two methods, one by the meteorologist and the other by the computer. The data needed includes surface and upper air measurements of pressure, temperature, moisture and wind.

A paper describing these techniques and procedures was presented at a Workshop on Safety of Ocean Racing Yachts by Mr. Patrick Sullivan (1999). (ref. 11)

The data is arranged on a grid on numerous levels from the surface to the stratosphere which may look like his figure 1, reproduced here as figure 7. The computer then processes the data to produce the forecast. There are many prediction models and they continue to be improved. A number of these models were used on Saturday 26th December and none predicted the highest winds.

Mr. Sullivan points out that patterns at the surface can be drastically changed in 6–12 hours by complex interactions high in the atmosphere. The intense low started to develop over western Bass Strait early on the 27th and had intensified to hurricane strength by 3.00 pm. It is considered by some that with a global grid, the grid points are too far apart (about one degree) to properly predict a local event.

Finer spaced regional models can be used which cover only a portion of the globe. A 25 kilometre resolution model was the basis of the 2.00 pm forecast by the Bureau of Meteorology on the Saturday 26th which predicted the 45–55 knot winds.

Even with this localized smaller grid, the computer model was too bland in its prediction.

Intense localized high latitude vortices that often resemble hurricanes have been observed in the northern hemisphere and the Sydney-Hobart storm may well have been one such. Emanuel and Rotunno (ref. 12) remark that polar laws appear to form in polar air with strong zonal flow aloft.

O.M. Phillips in a private communication remarked, "From what little information I had before, or have gleaned from what you sent, it seems that this violent occurrence was probably one of the very intense polar storms that have been identified in the last few years since the advent of polar imaging satellites. I have seen images of several arctic storms in the region north and west of Norway: They are characterized by a tight structure, true hurricane force winds but relatively small scale compared with low-latitude hurricanes. (In this sort of storm, the size is inversely proportional to the Coriolis parameter, the vertical component of the earth's rotation, which is of course largest near the poles). This is the first time I have seen what could be a southern hemisphere analogue. Because of the relatively small scale of the phenomenon, it is maybe not surprising that wind speeds measured some distance (50 or so km) away from the location of wind maximum, should be substantially less. It was clearly a very violent affair, and I am not sure present-day ocean wave generation models could provide good information on the waves, even if the wind information grid were dense enough to resolve the structure of the event".

Graham Mills of the Bureau of Meteorology Research Centre has subsequently reanalysed the data using five varying size grids (0.75° down to 0.05°) which has shown the development of the hurricane much more closely (ref. 13). This not only shows the intensity but also the localized concentration of the very strong winds. The more closely spaced grids forecast stronger winds greater than 30 m/s. The interaction of the variables are fully discussed in these two recent papers. Both authors, Mills and Greenslade, compared their revised analyses of winds and waves, respectively, with readings from stations that were located some significant distance (Wilson's Promontory, Kingfish B, Gabo Island)

from the location of the helicopter at the time of the rescue of the man lost overboard from Kingurra.

CONCLUSIONS

There is strong evidence which suggests one of the waves generated in Bass Strait on 27th December 1999 was the largest ever measured at 140 feet (42.7m).

The winds were of hurricane strength and were greater than 70 knots in speed.

The storm was localized and may have been a southern counterpart of an Arctic low.

Conditions appear to have favoured "quasi resonance" as the cause of the extreme waves. As well, a strong counter current of 4 to 5 knots associated with a swell from the north east of about eleven seconds period had a contributing effect.

Computer modelling of the weather with even more precise models applied after the event, were unable to predict the localised extreme events.

REFERENCES

(1) *Preliminary report on meteorological aspects of the 1998 Sydney to Hobart yacht race*. Bureau of Meteorology, February 1999.
(2) *Report of the 1998 Sydney Hobart race review committee*. Cruising Yacht Club of Australia, May 1999.
(3) *Coronial inquiry into deaths in the 1998 Sydney-Hobart race*. Statement by Senior Constable Darryl Jones 21590, Line Pilot, Police Air Wing.
(4) *Guide to Wave Analysis and Forecasting* WMO — No. 702 (1998).
(5) The Meteorological Office 1996: Hurricane Luis, The Queen Elizabeth and a rogue wave, *The Marine Observer*, 66: 134–137.
(6) *Seahorse*, October 1999. Letters, p.32 by Mike Kalaugher.
(7) *Seahorse*, July 2000. Letters, p.28 by John de Bruin.
(8) Big waves from polar lows. Dysthe, K.B. and Harbitz, A. *Tellus* 39A, 500–508, 1987.
(9) Development of freak waves near small intense lows and tropical cyclones. Callaghan, J. *7th National Australian Meteorological and Oceanography Society Conference Melbourne*, December, 1999.
(10) A wave modelling study of the 1998 Sydney to Hobart yacht race. Greenslade, D.J.M., Aust. Met. Mag., 50, 53–63, 2001.
(11) Can we predict the weather? Sullivan, P *Proceedings workshop on safety of ocean racing yachts*, University of New South Wales, Sydney Australia, 5–12 March, 1999.
(12) Polar laws as artic hurricanes. Emanuel, K.A and Rotunno, R., *Tellus*, 1–17, 41A, 1989.
(13) Mesoscale cyclogenesis in reversed shear — the 1998 Sydney to Hobart yacht race storm. Mills, G.A., *Aust. Met. Mag.*, 50, 29–52, 2001.

ANNUAL TASMANIAN ANTARCTIC MIDWINTER FESTIVAL
THIRD PHILLIP LAW LECTURE 19 JUNE 2004

By Greg Mortimer BSc, M Aust IMM; OAM

ANTARCTIC TOURISM — PAST, PRESENT AND FUTURE

[Reprinted from Aurora — September 2004, pages 2–5]

It is a great and somewhat formidable honour to be asked to give the Third Annual Phillip Law Lecture. It is hallowed turf, to be standing up here in the clear gaze of Phil let alone Ambassador Bowden and your good selves, and in the footsteps of the galloping intellects of Sir Guy and Barry Jones.

Antarctic tourism is a hot topic. White hot in fact. Earlier this month, the XXVII Antarctic Treaty Consultative Meeting in Cape Town dedicated an entire week to deliberations on Antarctic tourism. Over and above that we are in the middle of a battle for the hearts and minds of the general public on the issue of Antarctic tourism. Enter stage right, Steve Irwin, without crocodiles, bursting onto our Sunday news programs.

It is these things that I would like to talk to you about, hopefully to give you some thoughts for reasoned debate.

I come from a background in Antarctic science as a geologist, Antarctic adventures as a mountaineer and Antarctic tourism as a tour ship o gyrator. I am one of those very lucky people who has been imbued with things-Antarctican since childhood and have travelled to Antarctic about 100 times. In Australia, we have an extraordinarily high level of interest in all things-Antarctican, particularly given our small population. We teach it to our children in primary school. As you all well know, we have a long-term historical and genuinely deep interest. In the summer just gone (the 03/04 Antarctic season) Australians were the fourth most frequent visitors to Antarctica as tourists. In the 1997/98 Antarctic summer I had the very great pleasure of travelling with Dr Law back to East Antarctica, to Mawson and Davis stations in particular. We crossed the Southern Ocean from Freemantle, on the Russian icebreaker *Kapitan Khlebnikov* on that very long, non-stop leg. It was a tourist voyage organized by my company and Australian Geographic. The slow creep of a ship is a very telling way of getting a sense of the size of the Southern Ocean. We felt the gradual increase of cold air, we enjoyed the delights of watching albatross and our first iceberg and as we got closer to Mawson the excitement grew. There was a palpable delight throughout the vessel with the thought of going to Mawson with its founder. Radio communications with the base became excited and we could feel the tension from the men and woman waiting on shore. A band of solid sea ice barred a close approach so we took to the helicopters and flew the remaining 20 or so kilometres to shore. This was marvellous because we could see the full sweep of the polar plateau, then the tiny toehold of bare rock that houses Mawson. It was a memorable experience to enter the buildings with Dr Law and come face-to-face with a larger than life portrait of him on the wall.

After the fanfare had died down I was standing in the post office. Phil came along and said something quietly to me like: "I am just going outside and I might be some time". And I thought "Oh my God, he is going out to some ceremonial and poetic death in the bosom of his beloved Mawson Base". As Phil saw that thought flick across my eyes he reached into his pocket and bought out a great big cigar, a very big cigar. And said I bought this along especially just to celebrate and it might take a while". So he took himself to the edge of Horseshoe Harbour and quietly sat by himself.

I wonder what he thought sitting there, having seen this place go from bare rock to an icon of Antarctic science, the stuff of legends, and now to a landing site for tourists.

Where did it all start? How did it go from Scott's famous utterance: "Great God this is an awful place", to a voyage aboard a sophisticated vessel where passengers paid up to $30,000 for a ticket to see and feel this place?

Greg Mortimer is Australia's foremost mountaineer and managing director of Aurora Expeditions in Sydney which organises tourist cruises to Antarctica.

What is an Antarctic tourist?

In its broadest form presumably it is someone who pays to go.

It is an arguable point, but if we assume that, then perhaps the first Antarctic tourist was none other than Norwegian-born Australian resident Carstens Borchgrevink. He probably paid to go on the famous voyage of the whaling ship *Antarctica* in 1895. On that voyage Borchgrevink, somewhat controversially made the first human footfall on the main Antarctic continent at Cape Adare at the mouth of the Ross Sea. The bizarre thing about this then is that the first person to set foot on continental Antarctica may have been a tourist!

The 19-year-old Phillip Brocklehurst reputedly paid to go on Shackleton's 1907–1909 Nimrod expedition. In fact his mother is thought to have given a donation to Sir Ernest on the proviso that he took young Brocklehurst along. It is now thought that Titus Oates and Apsley Cherry-Garrard paid 1000 pounds each to go on Scott's 1910–1912 *Terra Nova* Expedition.

Of course these are just points of historical curiosity rather than being relevant to the debate we now are engaged in. But it does point out how the lines between great explorations, commercial activities and science have been intertwined from day one and the reasons for peoples' interest in Antarctica are varied and complex. Today we might not consider the thousands of sailors who visited the Antarctic Peninsula in the 1800's as sealers and whalers as real Antarcticans but I'll bet they were attracted by the adventure and the mystery, as well as the financial reward.

Antarctic tourism as we think of it today commenced in 1966 when Swedish entrepreneur Lars Eric Lindblad took a small ship of dedicated fare-paying passengers to the Antarctic Peninsula. Mind you, in 1956 (before the International Geophysical Year), 66 people overflew the Antarctic Peninsula in a Chilean national airlines chartered DC-8. Then in 1957 Pan American Airlines landed a commercial Stratocruiser flight at McMurdo Sound. And in 1958 Chile and Argentina took approximately 500 fare-paying passengers to the South Shetland Islands, at the northern end of the Antarctic Peninsula.

But it was Lars Eric who established the present-day model of using ships to transport enquiring people to Antarctica. These were wealthy people seeking the ends of the earth, wanting to learn and see and feel. They were educated along the way by naturalists, historians and glaciologists. He established the model of using purpose-built vessels as a

floating hotel/base camp with small craft such as rubber inflatables to ferry people to and from the shore. This is vitally important because it was the lessons learned from these early voyages and the consequent ethics of environmentally sensitive travel that provided the model for present-day Antarctic tourism. Remember this was done in the absence of government guidelines.

During the 1970s, flight-seeing over Antarctica became popular with the non-landing flights of Air New Zealand and QANTAS. These were tragically halted with the Mt Erebus plane crash in November 1979.

An interesting twist occurred in 1983 when the Chilean government used national military aircraft (Hercules C130s) to fly tourists to Marsh Station on King George Island. They were accommodated in military buildings called somewhat grandly "Estrella Polar" — the first hotel in Antarctica.

That essentially brings us to the present period. If you don't mind I will spend a little time explaining the present state of play. Bear with me.

Up until 1989 approximately 50,000 people had travelled to Antarctica and landed as tourists. During the 70s and early 80s numbers had waxed and waned. But 1989 was an important turning point because about this time sophisticated ice-strengthened vessels appeared on the scene fleeing the collapse of the Soviet Union. In that year three major tour ship operators developed an embryonic set of guidelines to manage a growing tourism industry.

These are "Guidelines of Conduct for Antarctic Visitors" and "Guidelines of Conduct for Antarctic Tour Operators". They are voluntary codes of conduct which have since been adopted by Antarctic Treaty Consultative Parties (as Recommendation XVIII-1). At that time the Antarctic Treaty had no mechanism to deal with Antarctic tourism and there was some debate as to whether it was worth worrying about. Then in 1991 the Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol) was signed and for the first time in modern history mankind looked at an entire continent as one environmental unit rather than a sum of its resources. In the same year seven tour operators formed the International Association of Antarctica Tour Operators (IAATO). Their aim was to act as a single organization to advocate, promote and practice environmentally responsible private-sector travel to Antarctica.

From then until now tourism has grown steadily and has diversified. We have now had almost 40 years of Antarctic tourism and a pattern has emerged. In the Antarctic season just finished, approximately 28,000 people visited as tourists (not including over-flights or government personal with time off visiting Scott's Huts or their local penguin colony). Of these, 21,000 actually landed. More than 90% of these people went to the Antarctic Peninsula.

Very largely, tourism has become a ship-based industry focused on the Antarctic Peninsula. Ships vary in size from 20 passengers to over 1000. Each person is paying between US$2,500 and US$20,000, but on average approximately US$5,000. Approximately 28 ships made 185 voyages to Antarctica, 180 of those were to the Antarctic Peninsula. Just as Lars Eric had initiated, these ships use small landing craft like Zodiacs to land people on shore at sites of wildlife, historical or natural-beauty interest. They are accompanied by trained interpreters who teach them about the natural history etc. both on the ground and in formal lectures and briefing sessions — to University of Antarctica field trip. We can now identify the sites and times that these people were ashore. Most of these people visited just 13 sites. They spend between nine and 21 days away from a South American port. They spend between one and five hours onshore at each place from ships lying between 100 metres and two kms from the shore.

But activities have diversified so that more people are taking options to dive, sea-kayak, climb and camp overnight. Approximately 23 yachts visited, giving longer stays and more bold adventurous activities. Also, a Chilean company flew a chartered aircraft across the Drake Passage to rendezvous with a 40-person ship for one voyage in Antarctica. In other words, a sound commercial tourist air link was established

Approximately 3000 people over-flew in commercial flights from Australia and Chile.

Approximately 400 people went to the Ross Sea region or East Antarctica and a further 180 were flown inland via the private air operator Adventure Network International to climb or traverse the ice cap.

IAATO has become an organization of 70 member companies. It has developed a set of 18 different sets of procedures to self-regulate activities. These include guidelines for:

- approaching wildlife onshore
- wildlife offshore such as seals and whales
- boot washing procedures for avoiding translocation of diseases
- parameters for staff experience

– guidelines for visiting next sites or scientific stations
– post-visit reporting procedures so that visitations can be analyzed.

Each company must submit an Environmental Impact Statement to its national authority. Two of these ships were not members of IAATO.

Any IAATO ship carrying over 500 passengers is not allowed to land those people. Any ship carrying between 200 and 500 passengers is strictly limited in the time and place of any landing. No more than 100 passengers are allowed ashore at any one time.

This season also saw several poorly prepared private adventure expeditions. I am thinking in particular of John Johansson's flight to the Ross Sea. I am a supporter of the notion of free, responsible access to Antarctica for all citizens. I firmly believe that the state has no right to make decisions about the level of risk that an individual is prepared to take. I have been involved in a number of very high-risk, some would say, outrageous private expeditions to Antarctica. I applaud John for his sense of adventure and his audacity. But he was ill-prepared. He had no fallback plan. Unfortunately he became an irresponsible expedition and very importantly he is an exception. I mention it because it is these singular events which are helping shape public and government opinion about Antarctic tourism.

I hope this gives you the picture that, at present levels, Antarctic tourism is minor. I believe that its environmental footprint is having no more than a minor or transitory impact on the environment. I believe it is essentially well-managed, structured and controlled, but there are a few loopholes in the system of governance that can be applied by the Antarctic Treaty System. However, I have watched the most-visited beaches in Antarctica (several places in the Gerlache Strait on the Antarctic Peninsula), throughout every summer for the last 13 years and there is no sign of visitation, no diminution of penguin populations, nothing. The work conducted by Scott Polar Research Institute during the mid-90s concluded that present methods were not sensitive enough to pick up influences of human visitation at these most-visited sites.

But what we do know is that continued care is needed in particular places and there is a strong feeling within the Antarctic community that we may be approaching critical levels of visitation which will require careful management in the not too distant future. These are not environmental disturbance issues but more to do with wilderness values.

Who are Antarctic tourists and what is the attraction of Antarctica?

We are all sorts of people. We vary in age from 5 to 90 and across the full social spectrum. We are generally well-educated, well-travelled, financially comfortable people from first-world nations. In the case of my company we are mid-40s average age.

We are attracted by the "other-worldliness" of Antarctica, its natural beauty, its history, its wildlife. Most importantly, I believe we are attracted by the notion of pure white wilderness, free of human intervention and this is the nub of our present debate. Antarctica has become the emotional symbol of the last unspoiled place. "Too important a place to be mucked up by humans, particularly tourists".

For those of you who know it, visiting Antarctica has a potent effect. It is the Antarctic paradox. It only takes a few days of being in a place so dominated by ice for your sense of colour, smell and sound to be effected. But the strange thing is that, rather than being depressed, these senses become enlivened. Your senses of smell and sound soar. Meanwhile the sun is doing unusual things in the sky, not setting or travelling around a flat ellipse. There are few other places like it to get a sense of large-scale natural forces at work. Is it any wonder that we are deeply effected, because it is somewhat like being on another planet. Out of that has come a fierce desire to protect — from those who go and from those who don't go.

It is these emotions that I believe, paradoxically, have got us into trouble in the last 15 years.

I believe that increasingly we are influenced by the concept that Antarctica is a fragile place but surely it is not a fragile system but a very robust one. The engine is driven by ice, by the polar plateau, by the Coreolis Effect and by the Southern Ocean. Disturbances in these can bring winds of 200 km per hour on our heads or calving of ice bergs 150 km long or variations in krill stocks that change the feeding pattern of marine birds and mammals. These are the big, powerful forces that dominate and are fascinating to see. Anyone who has stood in a katabatic wind at Commonwealth Bay knows all too well how puny the human body can feel. This is not to say, of course, that when we look in detail, there are not fragile places. Lichens in the Dry Valleys, moss beds in the Antarctic Peninsula and breeding grounds of the giant petrels are all sensitive treasures that need careful management. And of course it is these places that are often the focus of tourism.

Nor does it take into account that a single summer storm can eradicate an entire penguin colony or that one iceberg in the Ross Sea can block emperor penguins access to their nesting sites at Cape Crozier.

But the wider public debate about human interaction with Antarctica has increasingly focused on the fragility — without any further distinction, and this emotion is used to fire the debate about tourism. We hear it often in the press. In our popular press there is a growing image of a rapacious tourism industry that will stop at nothing to invade Antarctica. In fact our Federal Parliamentary Secretary for Antarctic affairs recently added fuel to the fire by referring in a press release to the "tourist invasion of Antarctica". Boat people invading our shore.

This is the emotion that "to be human is to err" that increasingly raises its head in environmental debate. That wherever we go we cause a problem. That we are separate from the planet, not a healthy part of it. Surely, the further we go down this path the less likely we are to find the answers we need.

And it is here that the Antarctic Treaty System (ATS) provides a remarkable model. Because Antarctica is the first continent where significant human activity (in modem times) has been preceded by a set of rules. We can argue about how effective the rules are but, nevertheless, the rules in one form or other were in place before significant tourism came along. Luckily enough, the people developing Antarctic tourism were environmentally aware and were driven by a love of the place rather than the buck. Underlying this is the preeminence of science and peace enshrined in the Treaty.

Three very important things happened at the Cape Town Antarctic Treaty Consultative meeting two weeks ago.

Firstly, a mechanism was found to regulate Antarctic tourism. This is a model for an accreditation scheme whereby any group involved in private activities in Antarctica would need to be accredited by the Treaty system to do so. This is a scheme that was driven by the Australian Antarctic Division (AAD) and IAATO. Its main value is to potentially provide the power of governance of the ATS over private activities.

Secondly, the principle that Antarctic tourism should have no more than a minor or transitory impact on environment was introduced — once again by the AAD and IAATO. This is a very major, albeit initial step in finding some limits to Antarctic tourism.

Thirdly, the Treaty parties agreed to discuss the notion of private infrastructure development and "land rights". This is a thorny issue because of national land claims in existence but in abeyance under the Treaty system. For example, if a large private hotel chain established a hotel near Mawson's Hut, who is to say whether they had ownership of the land after a number of years of occupation.

These three developments may provide the blueprint for Antarctic tourism for the coming decades.

So what of the future, what might tourism look like in fifty years and what do we need to know to be prepared?

Let me take a left-field approach to that. This Monday, 21 June, will not only be celebrated on Antarctic stations in anticipation of the return of the sun but, above the Mojave Desert in California, a small private company called Sealed Composites will be test-flying their rocket plane, attempting to win a US$ 10 million prize called the X-Prize. This is in the tradition of the great aviation prizes of the early 20th century that promoted the development of aviation.

The rocket plane will probably make the first private voyage into outer space. It has received some publicity but not too mach despite the importance of the event. To win the X-prize the craft must carry at least three people up to 100 kms and back again safely, twice within two weeks. It opens the way for individuals to go into space as tourists!

With that as an example of what might happen in tourism, I think it is better to look at Antarctica in a fairly pragmatic way rather than by suggesting scenarios.

If world tourism is any guide, Antarctic tourism is here to stay. The main reasons being that:

1. It is such an exceptional place.
2. The Antarctic Treaty recognizes tourism as a legitimate use.

As in other parts of the world, once the tourism industry has a good model it tends to stick to it. It is quite conservative in that way. Game viewing in the parks of Africa is a good example. Therefore for the next 10 years I believe the Lindblad model of ship-based activities will dominate.

It seems likely that the Antarctic Peninsula will remain the focus of attention because of the proximity of ports in Chile, Argentina and the Falklands to the Peninsula.

IAATO has found it very difficult to estimate the future numbers of tourists but my personal view is that we will see a growth of 50% over the next decade. We expect the average size of ships to increase because of the large number of available vessels in the 200 to 500 and 500-plus passenger

categories. We believe that the current moves within the Treaty system and IAATO will provide some mechanism for capping growth.

In this model, the numbers of people leaving from Australia and New Zealand are likely to remain small, perhaps 1000 to 2000 per annum. This is due mainly to the long time at sea from our ports to the Antarctic coast.

Speaking as a mountaineer I expect there will be a significant rise in the number of people travelling by yacht or even small ship to the Antarctic Peninsula, the reason being it is a climbing and adventuring mecca with hundreds of beautiful unclimbed peaks. Sea kayakers, divers and flyers will be drawn to this wonderland.

However, it is the prospect of air connections that makes it difficult to predict the future, because air links would produce a different model of tourism, particularly if supported by government logistics.

For a number of years there has been a cloudy mix of government-supported private tourism through the Chilean station or King George Island and last year a Chilean company flew a privately-chartered flight of tourists into the airfield to rendezvous with a small tourist ship. If this model develops, it could significantly increase the number of people visiting Antarctica, particularly if supported by government.

We believe there is strong public demand for air travel particularly from Australia and New Zealand because it solves the problem of the long ocean passage. And we believe that this development is highly likely, maybe in the next decade but certainly beyond.

Well into the future I believe we will see a limited number of ground stations where conventional tourists will fly for a touchdown or a multi-day stay. I believe that our perception of Antarctica as a sacred site unfit for human visitation will change, particularly if we start going into space.

And of course, to be prepared for this future we need good science models which include humans in the natural systems.

In summary, perhaps a little idealistically, I believe we have been given a golden opportunity.

Antarctica is a precious laboratory. Through science we can gain an understanding of large global forces. The discovery of the ozone hole is a fine example. Also we can gain an understanding of human impacts on the populated regions of the planet by observing the atmosphere, the Southern Ocean and the ice.

If we take the opportunity, we may well also gain a better understanding of our place in the system by observing our small-scale impacts on an untramelled place rather than by saying our impacts are impure.

Instead of saying "Don't go", why not say "Go, but go with small steps". Use science to take us forward, because I believe that in the robust natural system of Antarctica we have room to move and humans are not incompatible but are a healthy part of it .

If you really want to get a sense of how humanity and scientific scrutiny and the nobility of people being people in Antarctica are all in one, I recommend you read Phil Law's "You have to be Lucky".

ROYAL SOCIETY OF VICTORIA LECTURE — 16 NOVEMBER 2004
THE JUBILEE OF THE ESTABLISHMENT OF MAWSON STATION

Dr. Phillip G. Law, A.O., C.B.E.

Dr. Phillip Law, AO., C.B.E., introduced by Bob Lachal (Master of Ceremonies)

When tonight's celebration was raised some six months ago and it was suggested that I be M.C. for the evening I hesitated to accept. It was not because I did not want to do it, it is just the fact that in the Station's 50 year history, there are many more worthy expeditioners than myself. However I am overcome by the joy of being part of this historic occasion and I feel very honoured to be here.

Before getting the evening started I need to set the record straight. It would be ludicrous for me to M.C. this evening having not been to Mawson. I spent 14 months at Mawson from late 1964 to early 1966 as the Assistant Cook. Imagine the thrill of being selected to go to Antarctica at 21. I would have gone for no pay.

In Phil's time as Director of the Australian National Antarctic Research Expeditions he interviewed every expeditioner in an attempt to form an harmonious team. Years later he told me that he knew if you would be selected the moment you walked through the door.

The four months of training prior to going south involved some exciting experiences in helicopters, firing rocket lines ashore at Port Melbourne, bivouacs in the bush at Aireys Inlet where Phil would take off through the bush like a scrub turkey and you were going to keep up, painting the work boat 'Lillipod' in the Maribyrnong River.

The year at Mawson taught me the meaning of resourcefulness. After a year at Mawson, I knew Morse code, became a reasonable diesel mechanic and ham radio operator, and could operate all the plant equipment. I understood cosmic rays, the ionosphere and aural physics. I could handle a dog team and make beer. I really understood Frank Hurley's philosophy "If you can't find a way — make one."

In researching for tonight I found my 1965 diary and it took me back to motorbike rides on the sea ice and evening walks along the ice cliffs. It was a year I will always remember and tonight it is my pleasure to introduce the person who made that possible for me, and now I have the privilege of calling my friend.

Ladies and gentlemen, the founding Director of the Australian National Antarctic Research Expeditions, Dr. P.G. Law.

DR. LAW

Australia's permanent presence in Antarctica began with the establishment of Mawson Station in 1954. This event is the most important one in Australia's Antarctic history and it is most appropriate that its 50th Anniversary is being celebrated tonight by The Royal Society of Victoria.

I begin by paying a tribute to the pioneer party of ten men, led by Robert Dovers, who spent the first year at Mawson constructing the station and exploring the surrounding region. Few people have reflected upon the degree of isolation which they experienced.

In 1954 Antarctica was almost completely uninhabited. South of South America, on the Antarctic Peninsula, about 30 men manned a few small bases owned by Britain, Chile and Argentina. On the opposite side of the continent were our ten Australians. The rest of the vast continent was empty. The situation was similar to placing 30 men on Cape York Peninsula in Queensland and ten men at Perth in Western Australia.

The isolation of the Mawson party was absolute during the long winter months. If any emergency had arisen to threaten the group, no help could have been afforded them. There was no existing capacity in 1954 to provide succour by sea or by air.

The Mawson Station 1954 wintering party comprised:

Robert Dovers	Officer-in-Charge and Surveyor
Robert Summers	Medical Officer
Lem Macey	Technical Superintendent and Radio Operator
Bill Storer	Radio Operator
Bruce Stinear	Geologist
Bob Dingle	Weather Observer

John Russell	Diesel Mechanic
Bill Harvey	Carpenter
Jeff Gleadel	Cook
and	
George Schwartz	French Observer and dog handler

Involved in setting up the station were the following:

Captain H.C. Petersen	of the Kista Dan, and his crew
Dick Thompson	Voyage Superintendent and my Deputy
Arthur Gwynn	Medical Officer
Jim Brooks	Geophysicist
Peter Shaw	Meteorologist
Ken Dalziel	Radio Operator
Merryn Henderson	Weather Observer
Don Sweetensen	Cook
Andre Migor	French Observer
Flt Lieut. Doug Leckie	Pilot and leader of the RAAF Flight
Flt Sgt Ray Seaver	Pilot
Sgt Frank Morgan	Aircraft fitter
and myself.	

Of all these, only nine are alive today. Present here tonight are: Dick Thompson, Ray Seaver, Bill Storer and Jim Brooks. And I have received apologies from Doug Leckie, Bob Summers, Peter Shaw and Bob Dingle.

Few people in Australia today will stop to contemplate the complex problems involved in the Mawson exercise, so I will lead you through the major moves. We have to go back to 1949 when the Government created the Antarctic Division of the Department of External Affairs and, on 1st January, appointed me as the first Director. ANARE had been set up sixteen months earlier, with a skeleton staff and a temporary home in the Army Barracks in St. Kilda Road. Heard Island and Macquarie Island ANARE Stations had been built in 1948 under the direction of my predecessor, Stuart Campbell.

My first big task was to build a permanent headquarters for administrative staff and design an overall scientific program. My second task was to develop these programs at Heard and Macquarie, and plan for an ultimate Antarctic station. The big problem with the latter was to find a suitable ice-creaking ship — a job that took me five years.

During this time, I was able to gain valuable Antarctic experience by arranging to be appointed Australian Observer with an international expedition — the Norwegian British Swedish Antarctic Expedition. I joined them in Cape Town in the 1949–1950 summer and spent three months in the Weddell Sea and in Queen Maud Land, watching the expedition discover a site and then build a station.

In 1952, when that expedition concluded, I managed to buy one prefabricated hut that they had left on the wharf at Cape Town and two Auster aircraft that they had used for air support. Looking back, I marvel at how I persuaded Treasury to fund these purchases in 1951 when I still had no specific plans for an Antarctic venture. These purchases turned out to be of fundamental importance, for the hut became Mawson's first living quarters and, without the Auster aircraft, I could not have found the Mawson site.

Well, after finally discovering the ship *Kista Dan* in Denmark in 1952, I drew up a plan to use the ship in 1954 for an attack on the Antarctic Continent and submitted it to the Commonwealth Government for approval, which fortunately was given. What helped this approval was my proposal to close the Heard Island station and transfer huts and equipment from there to the Antarctic site.

Where to put such a station was the next problem. The U.S. Navy in 1948–49 had circumnavigated Antarctica and taken aerial photographs of much of the coast ("Operation High Jump"). I wrote to the Australian Ambassador in Washington and asked him to procure for me photographs of certain parts of the coast of Australia's Antarctic Territory.

I examined these with a magnifying glass, looking for a rocky site. (Most of the coast of Antarctica is ice cliffs.)

On that part of the coast with a longitude roughly that of Sri Lanka, I found two possible rock sites. The larger one was horseshoe-shaped and I hoped the arms might embrace a suitable harbour for a ship.

Another preparation I made was to send one of the men from the 1948 Heard Island party to winter in Antarctica with a French Expedition to gain experience. This man, Robert Dovers, I then appointed to lead the Mawson party.

Another preparation I had made was to procure husky dogs and breed and train them for two years at Heard Island.

Choosing the party was not a major problem — many good men applied and some I chose, like Dovers, from earlier parties. Also, the RAAF undertook to provide a team to fly and maintain the Auster aircraft.

Purchasing the supplies required for a wintering party in Antarctica is a difficult task. A station is a small village and with the exception that, at Mawson, there would be no children or women or gardens, one had to provide a huge variety of articles — huts, electric generators, diesel engines, vehicles, victuals, clothing, pharmaceuticals and medical operation equipment, radio transmitters and receivers, scientific equipment, entertainments, furnishings, library, and hosts of spare parts. Our past experiencewith purchases for Heard and Macquarie was invaluable. And I asked the French authorities, who maintained a station at Iles Kerguelen, north of Heard Island, to place ship fuel there for *Kista Dan* to pick up.

Another preparation I had made was to prefabricate two accommodation caravans to provide living quarters for the Mawson party while their huts were being erected. Expecting difficult landing conditions, we constructed floating "barge caravans".

In due course, *Kista Dan* sailed from Melbourne on Monday 3rd January for, first, Heard Island and, then, south to Antarctica.

At Heard Island we picked up some men and selected a group of Huskies, then sailed for Kerguelen, about 300 miles north-west. There we took on fuel and water and a couple of Weasel over-snow vehicles bought by us from the French expedition. Then "Southward Ho!".

On 1st February we entered the pack ice belt surrounding the Antarctic Continent. The next day, using an Auster mounted on floats, pilot Doug Leckie took off from an open pool with me on board to search for the two alternative rocky sites I had chosen from the American photos. I found that the smaller site was of no value, but the larger horseshoe-shaped site looked promising, so I decided to make it our objective.

On 3rd February, with the Austers on skis, the RAAF flew photo flights east and west of Horseshoe Harbour while the ship slowly backed and charged to carve its way through heavy pack ice.

On 4th February, Leckie flew Dovers in to inspect the site. They landed on the frozen sea ("float ice") outside Horseshoe Harbour. Dovers liked the site.

On 5th February, Leckie flew me there but we had an exciting landing, almost crashing into a large grounded iceberg. Meanwhile, I had decided, as the ship's progress was so slow, to send Dovers and several others by Weasel transport over the pack ice and fast ice to reach Horseshoe Harbour and start operations ashore. They towed the two barge caravans and set out on a 40-mile trip.

Next day, 6th February, the wind rose to over 50 knots and Dovers, who had not reached the shore, was forced to tow the barge caravans up on to the shore of a small rocky island one mile north of Horseshoe Harbour.

The wind had a disastrous effect on the pack ice and unbroken fast ice. Huge pressures were generated in the ice which cracked and broke up into ridges. Caught in this, the ship was subjected to immense pressure by the ice and I at first feared it would be crushed, like Shackleton's vessel. But then I saw that the pack ice was breaking up against the ship's hull, which was obviously stronger than the ice. Nevertheless, the ice piled up against the sides of the ship and tumbled in over the gunwales onto the deck. The ship listed heavily on one side.

I was worried about the Dovers party but finally made radio contact and was relieved to learn that they were safe on the island. But the ship situation was bad. The Captain was quite unable to move it, so teams of men began the huge task of digging ice away from around the hull.

I suggested using explosives beneath the ship to break up slabs of ice forced down beneath the keel, but the Captain was reluctant to do this. He unloaded all the anchor chains onto the ice to reduce the weight of the bows, set up ice anchors connected to winches on board and tried with full power to back off, but without result. Digging continued all day on the 7th and 8th, then finally on the 9th the Captain ordered explosives beneath the hull and huge slabs of broken ice splurged up and the ship dragged itself clear. Meanwhile, Dovers had pushed on and had set up camp at Horseshoe Harbour.

On 10th February, the ship began to move more freely than before because the storm had weakened the ice and cracked many areas. I flew in to the site and, with Dovers, chose locations for the huts.

I need not proceed with detail. On the evening of 11th February, the ship entered Horseshoe Harbour. I was afraid that a submerged reef might join the arms of the horseshoe entrance. There was a reef but fortunately the water above it was deep enough to permit the ship to cross and anchor in deep water inside the harbour.

During the night violent winds wrecked one Auster aircraft tied down on the deck of *Kista Dan*.

Two days later, with unloading half finished and construction of huts proceeding, I gathered the men

around a flag pole beside the caravans, raised the Australian flag, and said:

"In the name of Her Majesty Queen Elizabeth the Second and the Government of the Commonwealth of Australia, I raise the Australian flag on Australian Antarctic Territory and I name the site of this new ANARE station "Mawson" in honour of the great Australian Antarctic explorer and scientist, Sir Douglas Mawson."

On 24th February, with the wintering party well established, we said goodbye and left Horseshoe Harbour. From Mawson we sailed eastwards to attempt a landing at the Vestfold Hills about 350 miles away. It is a remarkable region of bare ice-free rock, dotted with lakes and covering an area of about 200 square miles. I had seen aerial photos of it taken by the Americans. We reached the region and spent 2nd–4th March there, landing at two places.

After leaving the Vestfold Hills on 5th March, we ran into a fierce hurricane with winds gusting to over 140 mph. Our second Auster aircraft tied down on deck was destroyed. The Captain lost control of the ship, which lay side-on to the wind and rolled between vertical and 70°. For 26 hours we were in danger of capsizing, drifting with the wind through pack ice and icebergs. It was the most terrifying experience of my adventurous life. Luckily we survived.

ALIENS IN OUR WATERWAYS!

ADRIAN WELLS, MURRAY DARLING ASSOCIATION, ALBURY

PRESENTATION TO THE ROYAL SOCIETY OF VICTORIA AT ECHUCA ON 7 NOVEMBER 2003

In the last 30 years, there has been a great deal of community and government activity to rehabilitate degraded land and water resources along our rivers systems. However, most of this work has focussed 'above the water'. It is only in recent years, that we have started looking 'below the water' in our river systems to start to understand and address degraded river habitats, alien fish and declining native fish numbers.

Healthy, diverse and productive native fish communities are vital parts of healthy rivers in the Murray–Darling Basin. Native fish provide significant cultural, environmental, recreational and economic benefits. But a major threat to healthy waterways and vibrant native fish populations is the ongoing invasion and spread of introduced exotic fish. There is a growing concern about the impact of these introduced or alien fish. A small, but growing number of these alien fish, are now regarded as invasive pests, such as carp, tilapia and oriental weatherloach.

While knowledge about carp and their impacts are reasonably well known, there is relatively little understanding about the impacts of other alien fish. Impacts can include competing with native fish for food or space; eating native fish or their eggs; spreading disease; affecting water quality; and degrading habitats.

PEST OR ALIEN?

There is a lot of community debate on how to define fish that are not native to the Murray–Darling Basin. Some recreational fishing groups are reluctant to refer to some introduced fish as either *alien fish* or *pest fish* as they have been stocked in rivers and lakes for over 100 years, sometimes with government support (e.g. redfin). Some fish are seen as providing food for native fish and not damaging the environment, while trout fishing provides significant economic and social benefits for some communities.

Others regard all introduced fish as pests, pointing out that they have affected native fish and their habitats. There is also concern that by labelling some alien fish as pests, it may focus attention on simply getting rid of the fish and not addressing the real issue of degraded river habitats that encouraged invasion by alien fish in the first instance. A good example of this tension is carp.

CARP — VILLAINS OR VICTIMS?

Sometimes called 'rabbits of the river', the introduced carp is Australia's most abundant yet most despised large freshwater fish. They are accused of a multitude of problems that plague our inland river systems, from the decline of native fish to degrading habitats.

While often referred to as *European Carp*, carp actually originated in central Asia, spreading from China and Japan to southern Europe. It surprises many Australians to learn that carp are one of the most widely distributed freshwater fish and are the most farmed and eaten fish species in the world.

It also surprises many Australians to learn that carp were brought to Australia in the 1850's for fishponds by acclimatisation groups, the same groups that also introduced rabbits, foxes and blackberries. Carp were also brought to Sydney and the Murrumbidgee Irrigation Area to control waterweeds but these carp never became a problem.

Adrian is a founding member of the National Carp Task Force and is project manager for the Murray Valley Trail. He has served on the Community Advisory Committee of the Murray–Darling Basin Ministerial Council and the NSW Murray Catchment Management Board. He currently chairs the Community Stakeholder Group for the Murray–Darling Basin Commission's Native Fish Strategy.

In 2002, Adrian was awarded a Community Services Award by the Victorian Government for services to education, including environmental education.

Carp became a nuisance in the 1960's when they were illegally imported from Germany and escaped into the Murray River near Mildura during a flood. They are now widely distributed throughout south-eastern Australia, with smaller populations in Western Australia and Tasmania. They certainly dominate fish communities in the Murray–Darling Basin, they comprise up to 90% of all fish in some areas.

Since carp first came to Australia, our inland river systems have suffered massive changes. River regulation, altering natural flows, farming, urban development, and removing snags have all impacted on our rivers and native fish. These activities have created ideal environments for carp while disadvantaging native fish.

HAVE YOU SEEN THIS FISH

Carp can be identified by the two barbels or whiskers on either corner of their upper lip. Other distinguishing features include a forked tail, single dorsal fin and large scales. They are usually bronze or olive-green in colour.

Their growth depends on access to food, water temperature and population densities. However, they can grow as large as 17 kg. They are long-lived and prolific breeders; females can produce up to 300,000 eggs per kg of body weight.

FACT OR FICTION?

Carp have been well-studied overseas although little research had been conducted on wild carp until quite recently. Despite the growing interest by the community, researchers and governments in carp, there is still a great deal of misunderstanding and confusion over what carp do. Knowledge of carp in Australia is still relatively basic, but it is essential to develop effective control strategies.

The bottom-feeding habits of carp, which disturb sediments, have been blamed for muddying our rivers. Turbidity does increase in enclosed waters with high numbers of carp and low food levels. But overall, poor catchment management practices are more likely to cause erosion and create increased river turbidity.

Carp are accused of contributing nutrients to waters and of eating daphinia water fleas that predate on algae. Studies show that carp only recycle the nutrients already in the aquatic environment. Other studies indicate that low river flows have created environments suitable for the growth of these toxic algae.

There is plenty of evidence that carp dislodge aquatic plants through their bottom feeding behaviour. This deprives native fish of food and prevents disturbed plants from re-establishing, leading to the permanent removal of water plants from many habitats and which provide vital food and habitat for fish and invertebrates. Increased turbidity can also reduce penetration by sunlight, affecting aquatic plant growth and adding to water nutrient levels.

Carp have been observed feeding around roots and undermining banks and irrigation channels, resulting in trees falling into waterways. However, research shows that river regulation, which alters river levels frequently and often suddenly, is more likely to decrease bank stability. Removal of bank vegetation, over-cultivation and stock access are other factors that contribute to bank erosion.

While they may accidentally swallow native fish eggs as they feed, carp are more likely to be hunted, rather than be hunters. Carp don't have grasping teeth necessary to hold struggling prey such as fish. However, young carp are increasingly eaten by Murray cod and Yellow Belly.

Carp compete with aquatic animals for food and habitat sites, but the reduction of native fish numbers in our river systems has created a space that carp now occupy. Carp lay their eggs at lower temperatures and earlier than many native fish and are unlikely to encroach significantly on spawning sites. Carp eat zooplankton, the same food that many young native fish eat, but most adult native fish eat different things from carp.

CARP CAN BE USEFUL

Many Australians are unaware that carp are a resource and have been fished commercially and recreationally since the 1960s. Several successful commercial carp ventures have been established in Australia. Carp are currently made into fertiliser, fish bait, stock feed, berley, fish seasoning and canned fish. Processed carp and carp eggs are exported to Eastern Europe and Israel and there are potential carp markets in southeast Asia.

Carp are provided for the restaurant trade while some are exported. You can cook and eat carp, there are even cookbooks listing delicious carp recipes. You can also turn carp skin into valuable and attractive leather products.

WHAT IS BEING DONE ABOUT CARP?

Despite the warnings issued by the Murray Darling Association and a number of scientists in the 1960's (including Dr Dunbavin Butcher, a past-president of The Royal Society), carp escaped into the waterways of the Murray–Darling Basin in the 1960's. In the 1990's (after 25 years of very little action or research), community concerns about carp started to grow. The National Carp Task Force was established in 1996 to advocate for an integrated approach to carp management and control in Australia. One of its first tasks in 1996 was to convince the Murray–Darling Basin Ministerial Council that the Murray–Darling Basin Commission should take a greater role in carp management.

In 1998, the Federal Government provided funds to support increased research and establish a carp control coordination group. In 2000, a national carp management strategy was launched. In 2002, the Murray–Darling Basin Commission's Native Fish Strategy was announced. In 2003, the daughterless carp project began.

In collaboration with local communities and natural resource managers, scientists are investigating several ways that carp might be controlled in Australia. However, the answer to controlling carp will lie with an integrated approach.

Fishing can significantly reduce carp numbers in enclosed and small waterways. Commercial fishers in Victoria, South Australia and NSW have continually and successfully fished carp since the early 1970's. In some parts of South Australia, fishing has reduced carp from 80% to less than 40% of the biomass. Electro-fishing is a humane method and is effective in certain circumstances for its ability to target carp. However, it requires qualified operators to ensure that native fish are not affected.

A number of community groups have successfully removed carp from wetlands and prevented them from re-entering by screening inlet channels. These efforts remind the community that the invasion of carp is a relatively recent occurrence, and that removing carp can have a dramatic impact on the environment. Scientists are also experimenting with controlling carp by manipulating water levels of wetlands, lakes and billabong that are controlled by regulators.

Carp have been successfully eradicated from lakes using poison. However, the widespread distribution of carp limits the use of poison to enclosed lakes or dams. Using large amounts of poison to control carp is likely to have significant detrimental impacts on native plants and animals. Poisons can also be costly.

Scientists first investigated using a virus to control carp in the 1970's when carp in Europe were struck with a virus called *spring viraemia*. However, the virus is not an option at this stage because introducing such a virus may affect native fish and Australian agriculture's 'clean-green' status.

Carp succeed in disturbed environments as native fish populations decline. Therefore, restoring the resilience and resistance of our ecosystems by reversing some of the human disturbances they have suffered, will contribute to addressing the carp problem. Improved river flows may restore the numbers and diversity of native fish predators such as the Murray cod, which now feed on young carp. Providing effective fish ladders with carp traps will help migrating native fish recolonise waters upstream of weirs and dams while trapping carp. Restoring riparian vegetation will encourage native fish and other aquatic animals that prey on carp eggs and young carp or compete with them for food or space.

Programs to restore river ecosystems are already in place in many areas. They include the work of government agencies, Landcare groups, catchment management organisations, Local Government, community groups, and researchers. Improving water allocations to balance social, environmental and economic needs will also help to control carp.

DAUGHTERLESS CARP

Biological control is considered to have the most promise for carp control and has become a reality with the launch of the daughterless carp project in early 2003. Daughterless carp technology was developed by CSIRO and aims to block the development of females and produce exclusively males. It is predicted that this genetic technology could sharply reduce carp numbers in the Murray–Darling Basin within 20–30 years of release.

The daughterless carp program is part of the Murray–Darling Basin Commission's *Native Fish Strategy* and is being managed by the Pest Animal Control Cooperative Research Centre. The technology is likely to be most effective when used in conjunction with other carp control methods. The vision of the daughterless carp project is to provide a biologically sustainable option for the control of carp in the Murray–Darling Basin within the context of

improving overall catchment and waterway management, as well as within the Commission's broad natural resource management agenda. However, it is a high-risk, expensive and long-term research project.

Research on the fundamental genetics of daughterless carp has started in secure laboratories at CSIRO in Hobart. The initial research is being done on Mosquito Fish, which has a much shorter life cycle than carp and will facilitate testing of the daughterless gene over a number of generations in a short time. Also, Mosquito Fish are a pest fish in their own right and the daughterless carp technology could even be applied to Gambusia and other pest fish if proven successful. Once early research is satisfactorily completed, trials will be conducted in the laboratory over a number of generations to assess whether the daughterless gene can persist in the population.

The daughterless carp project is a very exciting venture and is already generating more research into carp. This includes an assessment of wild carp populations for release strategies of the daughterless gene (to be conducted by NSW Fisheries and the Pest Animal Control Cooperative Research Centre).

PEST FISH — A DIFFICULT ISSUE

Managing any of the introduced or alien fish is not easy. There is a need to control established pests such as carp, tilapia and gambusia; to minimise the impacts of other alien species (such as trout); and to prevent the introduction of other alien fish. A coordinated approach involving federal, state and local governments and the community is vital.

Managing alien fish in isolation will not have a significant impact on rehabilitating native fish. However, as part of an integrated approach, managing these fish will make a difference and contribute to the success of the Murray–Darling Basin *Native Fish Strategy*.

In contrast to pest plants and pest animals, there is often little perceived benefit for individuals in controlling highly invasive alien fish like carp. These fish usually occur in public waterways and wetlands. State and local governments and the public as a whole have responsibilities for the management of these fish through a partnership approach.

MORE INFORMATION

- *Cyprinus: Newsletter of the National Carp and Pest Fish Task Force* — for copies of this newsletter, phone 02 6021 3655
- National Carp and Pest Fish Task Force — phone 02 6021 3655 (for general information, posters, brochures, etc. on carp)
- NSW Fisheries — phone 02 9566 7802 for information or visit their website www.fisheries.nsw.gov.au
- Murray–Darling Basin Commission — phone 02 6279 0141 for copies of the following documents:
  - *National Management Strategy for Carp Control*
  - *Future Directions for Research into Carp*
  - *Ranking Areas for Action: A Guide for Carp Management Groups — Murray–Darling Basin Native Fish Strategy*
- Bureau of Rural Sciences website — pests/carpfact.htm
- AFFA Shopfront — phone 02 6272 5550 for copies of the Bureau of Rural Sciences book *Managing the Impacts of Carp.*
- Queensland Department of Primary Industries Call Centre — 13 25 23
- Queensland Fisheries Service web page — www.dpi.qld.gov.au/fishweb/
- Daughterless Carp Program — phone the Pest Animal Control CRC — phone 02 6242 1768

Adrian Wells has a background in horticulture, the media, rural counselling, community development and rural education. He currently works with the Murray Darling Association and is based in Albury-Wodonga. The Association has membership of some 90 councils along the Murray, Murrumbidgee, Darling and other rivers in NSW, South Australia, Queensland and Victoria.

The Association provides a major focus for Local Government involvement in the natural resource management issues of the Murray–Darling Basin, and is the largest non-government group with an interest in the environmental future of the Basin.

LOCAL GOVERNMENT AND NATURAL RESOURCE MANAGEMENT

CR BRIAN SHARP, MAYOR OF MURRAY SHIRE COUNCIL AND IMMEDIATE PAST PRESIDENT OF THE MURRAY DARLING ASSOCIATION

PRESENTATION TO THE ROYAL SOCIETY OF VICTORIA AT ECHUCA ON 7 NOVEMBER 2003

INTRODUCTION

Recent Australian environmental policy has increasingly placed greater emphasis on the community and Local Government to respond to environmental degradation and the decline of biodiversity.

However, the involvement by Local Government in managing natural resources can be characterised as highly variable, poorly understood by other levels of government, rarely appreciated, and probably underdeveloped.

Few would question the need for Local Government to be involved in conserving biodiversity at the local level. Poor management of native vegetation impacts on the productivity of land and affects the ability of councils to raise rates. A degraded environment impacts on infrastructure, public parks and roads. There is a growing community awareness of these critical issues, and corresponding community pressure on councils to address biodiversity and environmental matters. Local Government is also responsible for the management of large areas of land and long stretches of roads that are often the last but vital refuge of remnant vegetation and biodiversity stocks.

It is worth noting that Local Government was involved in the governance of the Murray–Darling Basin from the very beginning and was one of the catalysts to the Corowa Water Conference in 1902, where the local mayor presided over part of the event. One of the ancestors of the current Corowa Council's mayor chaired the Corowa water Conference in 1902. Local Government was also a key player, often behind the scenes, in the movement towards what is now the Murray–Darling Basin Initiative.

A BIG INVESTOR

Many people are surprised to learn that Local Government is a very big investor in managing natural resources across Australia. According to ABS figures, it is probably the biggest investor in the nation. In 1999–2000, municipal councils across Australia spent nearly $2.5 billion on environmental activities, far more than state and federal governments combined. This investment also reflects a change of focus by many councils in recent years that have seen environmental issues become second only to infrastructure management in many council priorities.

Examples of this significant investment range from relatively simple activities to quite complex and long-term integrated catchment management programs. While the aims may not specify a focus on biodiversity, many of the projects are delivering positive biodiversity outcomes for both land and water resources. Examples range from relatively simple courses in the Campaspe Shire in northern Victoria to teach grader drivers how to protect endangered roadside plants, to large integrated projects like the Coorong Council's efforts in South Australia to address salinity.

Projects include the Land and Water Management Plan areas in southern NSW where councils are partners in plans that will have considerable biodiversity outcomes in extensive irrigated areas. The plans involve roadside vegetation strategies, and strengthening native vegetation and wetland management on private property.

Many councils across Australia host and support Landcare Groups, support tree planting, work with schools and community groups, and participate in partnership programs with communities and governments. In 1999, councils spent nearly $110 million on tree planting and stopping land degradation. Councils also have a direct affect on private land development by attaching conditions to development applications when deciding statutory planning matters.

BIODIVERSITY STRATEGY

The National Local Government Biodiversity Strategy launched last year, recognises that while Local

Government is doing a lot in terms of protecting and enhancing biodiversity, it has the potential to do much more. The report showed that there is willingness by Australian councils to play a lead role in dealing with the loss of biodiversity, but it does require a clear and co-operative partnership between the three spheres of government.

The report highlights that in some of the more remote parts of rural Australia, there is often a lack of appreciation that the biodiversity requiring protection often covers huge areas. The resources required as well as the scope of day-to-day council activities can unfortunately limit their involvement in protecting the biodiversity. It is resources and scope of the problem, not a lack of willingness that is the limiting factor.

TRADITIONAL AND NEW ROLES

Philosophically, many councils would regard natural resource management as principally the task of state governments who are well resourced for this purpose. But at the practical level, councils are very much engaged in natural resource management, often through their more traditional day-to-day activities such as engineering, statutory planning, delivering water, managing effluent and rubbish.

Sometimes, these more traditional roles and the newer initiatives can become blurred. The large investment by Albury City Council (in southern NSW) to manage sewage is generally regarded as an effluent treatment activity. Yet that program has a huge and positive impact on water quality and biodiversity in the Murray River downstream of Albury. Determining a Local Government role in natural resource management is complicated by the great diversity of local governance in Australia. Council functions and responsibilities differ widely between and within each State. Councils are the local source of governance and self-management with the task of responding to local needs. Unfortunately, their role is seen to be small and is often not included in strategic considerations by the states.

RESOURCING

Funding support for natural resource management is also a key issue for many councils. Research by the Murray Darling Association shows that complexity of application processes, lack of on-going commitment and relatively short timeframes for programs deter many councils from embracing greater involvement in natural resource management because of fear of creating financially unsustainable precedents. The best examples of Local Government involvement in natural resource management are self-supporting programs that rely on, and build on, local community support for environmental issues, rendering them largely resistant to the problems of external funding.

EQUAL PARTNERS

It is encouraging to note the inclusion of Local Government representation on the new NSW catchment management boards, and the inclusion of people with local government expertise on the Victorian and South Australian catchment management boards. Many of these catchment organisations have biodiversity as major catchment targets.

However, there is still much more work required. Encouragingly, a large number of recently released natural resource management documents, including the Integrated Catchment Management policy document and salinity management plans for the Murray–Darling Basin, as well as the National Action Plan, all acknowledge a role for Local Government. Sadly, some documents fail to properly understand or grasp what Local Government is already doing and can do in the future to improve biodiversity. If Local Government is to be a legitimate participant in managing our fragile natural resources, then it must be treated as an equal partner around the table when policy, decisions and resource allocation are considered.

ENGAGEMENT AND PARTNERSHIPS

Sometimes the problem is exacerbated because no one takes the time to ask or engage Local Government in addressing the issues. Local Government efforts are often unrecognised, not celebrated or are poorly reported. A recent national report on the legislative ability of Local Government to conserve native vegetation had a 14-member project steering committee — only one member represented Local Government. The issue is also exacerbated by Local Government concerns that it is often excluded from planning national and state environmental initiatives that in time, can overwhelm or ignore council activities at the local level.

One area where Local Government does have capacity is its ability to forge a range of links with

other councils, groups and governments, in effective partnerships and cooperative programs. Some even reflect international co-operation. The international Local Agenda 21 program is a good example of Local Government being a key to effective management of natural resources

NATIONAL CARP TASK FORCE

Recent Australian reports document the growing effectiveness of regional organisations of councils addressing environmental issues as part of regional development programs. The 90-member councils of the Murray Darling Association were pivotal in establishing the National Carp Task Force that has played a key role in delivering a national carp management strategy, enhanced commercial opportunities for carp and a national carp awareness information and education program.

The work of the Task Force has resulted in a growing awareness by the community of the state of native fish, aquatic biodiversity, fish habitat, and the relationship between aquatic biodiversity and land management. This has contributed to the development of a native fish management strategy for the Murray–Darling Basin as well as various state initiatives to improve native fish habitats and aquatic biodiversity.

COMMUNITY INVOLVEMENT

One significant outcome of the National Carp Task Force is demonstrating the value of community involvement in biodiversity issues. The community has a wealth of knowledge, skills and experience to offer in the area of biodiversity. The community needs confidence that action is being undertaken and that the policies and actions are being implemented. Also, the community wants to be kept informed on achievements and is keen to be involved in management and research activities. Any work on biodiversity undertaken by researchers and governments must ensure engagement and partnerships with the community at all times as well as good reporting and communication strategies.

A FRAMEWORK

A scoping study on Local Government and integrated catchment management was recently finalised by the Murray Darling Association. The study is suggesting a framework for more positive engagement and involvement by Local Government in biodiversity and environmental issues. The framework is based around engaging Local Government; identifying a legitimate and acknowledged role; merging state and national plans to achieve consistency of approach and understanding; developing a bottom-up approach; and developing consultative processes that recognise the three levels of government (rather than just two as tends to currently occur). Such a framework would incorporate education and awareness; adequate and effective resourcing; provide data, information and expertise; and adopt a co-ordinated and partnership approach.

The report concludes that a serious dialogue between state and local governments would do a lot to improve relations and understanding of what local government can and cannot do as well as start to incorporate its involvement in strategic planning at the state levels. Over the past 12 months, the Murray Darling Association has been building on the outcomes of this major study. The Association is increasingly undertaking activities that demonstrate the growing capacity of Local Government to have a legitimate role in natural resource management.

The Association is underpinned by a growing network and support of its member councils, community groups, corporate supporters and individual members. This is not only valued by the Association but is the envy of other groups. It makes the Murray Darling Association the largest non-government organisation in the Basin with an interest in sustainable management of the Basin's natural resources.

THE LIVING MURRAY

The Federal and state governments recently announced a major investment in the Murray–Darling Basin as well as the completion phase of much of *The Living Murray* initiative. The much-anticipated first step decision about environmental flows for the Murray River by the Murray–Darling Basin Ministerial Council will be made later this year.

The Association and Local Government have been proactive on environmental flow issues. The Association has promoted the debate extensively; distributed material across the Basin about environmental flows; run workshops and forums; participated in various workshops; and encouraged the community to make responses. The Association also

planned and conducted the National Local Government Environmental Flows Conference at Mildura during July.

The Living Murray has met with a mixed reception from Basin communities. The Association notes that there is general agreement in the community that something has to be done about the state of the waterways and the over-allocation of water across the Murray–Darling Basin. Whatever the outcomes, Local Government and the Association want to ensure a strong and properly resourced role for Local Government in the consultation and implementation of The Living Murray as well as natural resource management across the Murray–Darling Basin.

Despite some concern in the community about *The Living Murray* and particularly the community consultation process, the Murray Darling Association welcomes the debate on *The Living Murray* and environmental flows. It is the debate that the community had to have. The Association also accepts that trying to get the best environmental flow or improved water outcomes for the Murray–Darling Basin is a highly complex process and there will be winners and losers.

A LEGITIMATE PARTICIPANT

Local Government and councils are very much legitimate participants in managing the fragile natural resources. Local Government is already involved and wants to be more involved as it aligns its futures with those of healthy catchments and biodiversity. However, as a legitimate participant, Local Government also expects to be treated with consideration and as an equal partner, particularly when policy, decisions and resource allocation are being undertaken.

NO SPECIAL FORMULA

There is no special formula for Local Government involvement in good natural resource and environmental management. It is a matter of following some basic rules of engagement that have been tried and tested by the Murray Darling Association and other Local Government groups and those who have created effective partnerships.

The challenge is to join the game. This requires getting the knowledge, maintaining the will, providing leadership, developing skills and enhancing capacity. It is about finding resources and supporting the players to get to the end of the game. And at the end of the day, make sure you celebrate the win!

It is also about making sure that when 'the ball is passed', you are a member of the team, not an innocent or unsuspecting bystander!

REFERENCES

AUSTRALIAN LOCAL GOVERNMENT ASSOCIATION 2000, *National Local Government Biodiversity Survey; National Local Government Biodiversity Strategy Implementation Project Stage* 1. Australian Local Government Association, Canberra, October 2000

BARTLETT, S., 1998. *Local Government involvement in natural resource management in the Murray–Darling Basin*. Prepared for the Murray Darling Association, September 1998

BATESON, P., 2000. *Incentives for Sustainable Land Management: Community cost sharing to conserve biodiversity on private lands. A guide for Local Government*. Environment Australia, Canberra and Environs Australia, Melbourne.

HULLICK, J., 2001. *Scoping study to investigate Local Government's role in Integrated Catchment Management*. Report to the Murray Darling Association Board. 2002

MURRAY LAND AND WATER MANAGEMENT PLANS, 2000. *Future Directions for 2000–2005*. Report to NSW Government Land and Water Management Plan Assessment Team. March 2000.

SHARP, B., 2000. *What is Local Government doing to address and to manage our natural resources*? Paper presented at the National Assembly of the Australian Local Government Association, Canberra, December 2000.

THORMAN, R., 1999. *Local government good examples* In Australian Farm Journal, August 1999.

SUPPLEMENTARY NOTES ON THE SUBGENUS *LOXOCYTHERE (NOVOLOXOCYTHERE)* WARNE AND SOME COMPARABLE OSTRACOD TAXA.

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Abstract

Brief supplementary comments to those of Warne, 2004a for the subgenus *Loxocythere (Novoloxocythere)* are here given, which further differentiates the carapace of this taxon from some other ostracod genera. Also included are two corrigenda pertaining to Warne, 2004a and 2004b.

Introduction

Comparisons made by Warne, 2004a between the subgenus *Loxocythere (Novoloxocythere)* Warne and various other ostracod genera/subgenera are here briefly expanded upon. Details of the specimens illustrated here are as in Warne, 2004 a & b.

COMPARATIVE MORPHOLOGY

Loxocythere (Novoloxocythere) pelius Warne is similar in external appearance to the schizocytherine ostracod *Schizocythere batjesi* Keij (sensu Keen, 1982). However most species belonging to the similarly shaped genera *Schizocythere*, *Cnestocythere* and *Apateloschizocythere* possess a quadrate or subquadrate inner margin, whereas *Loxocythere (Novoloxocythere)* species tend to have a triangular to subtriangular shaped inner margin. The hinge structure in species of *Loxocythere (Novoloxocythere)* (fig. 1B) is much simpler than in most schizocytherine species (i.e. *Schizocythere inexpecta* McKenzie, Reyment and Reyment *sensu* Majoran, 1996 from the Palaeogene of S.E. Australia).

Loxocythere (Novoloxocythere) species are also similar in external appearance to the perissocytherine ostracod *Gangamocytheridea dictyon* van den Bold, 1963. However the later, like most perissocytherine species, possesses a subvertical elongate sulcus situated above mid height and at approximately mid length, on the lateral surface of the carapace. This conspicuous ornamental feature is not present in species of *Loxocythere (Novoloxocythere)* (fig. 1A).

CORRIGENDUM 1

Key images incorrectly published at low resolution in Warne 2004a and Warne 2004b are here reproduced as high resolution images (fig. 1).

CORRIGENDUM 2

The paragraph headed "*Antarctiloxoconcha* Hartmann, 1986" in Warne, 2004a should read as indicated here in the following paragraph. Except where related to cited references, figures mentioned in this corrigendum pertain to the figures in Warne, 2004a.

Antarctiloxoconcha Hartmann, 1986

This group includes rotund species with subquadrate inner margins and posterior extremities well below mid height. Species belonging to this genus include *Antarctiloxoconcha frigida* (Neale, 1967) (type species), and possibly *Antarctiloxoconcha? malzi* (McKenzie, et. al., 1993) n. comb. *Antarctiloxoconcha? vermiculatum* (Whatley, et. al., 1988) n. comb. *Antarctiloxoconcha? phaseolus* (Neil, 2000) n. comb. and *Antarctiloxoconcha? burdwoodbankensis* (Whatley and Cusminsky, 2002) n. comb. (although a number of the latter four species may ultimately warrant separate subgeneric status). Hartmann, 1986 regarded the type species as belonging to the Loxoconchidae Sars while Neil, 2000 originally regarded the species *Antarctiloxoconcha? phaseolus* as belonging to the family Eucytheridae Puri. Whatley et. al., 1998 considered the species *Antarctiloxoconcha frigida* to be a cytherurid placing it (with reservation) in the genus *Cytheropteron*

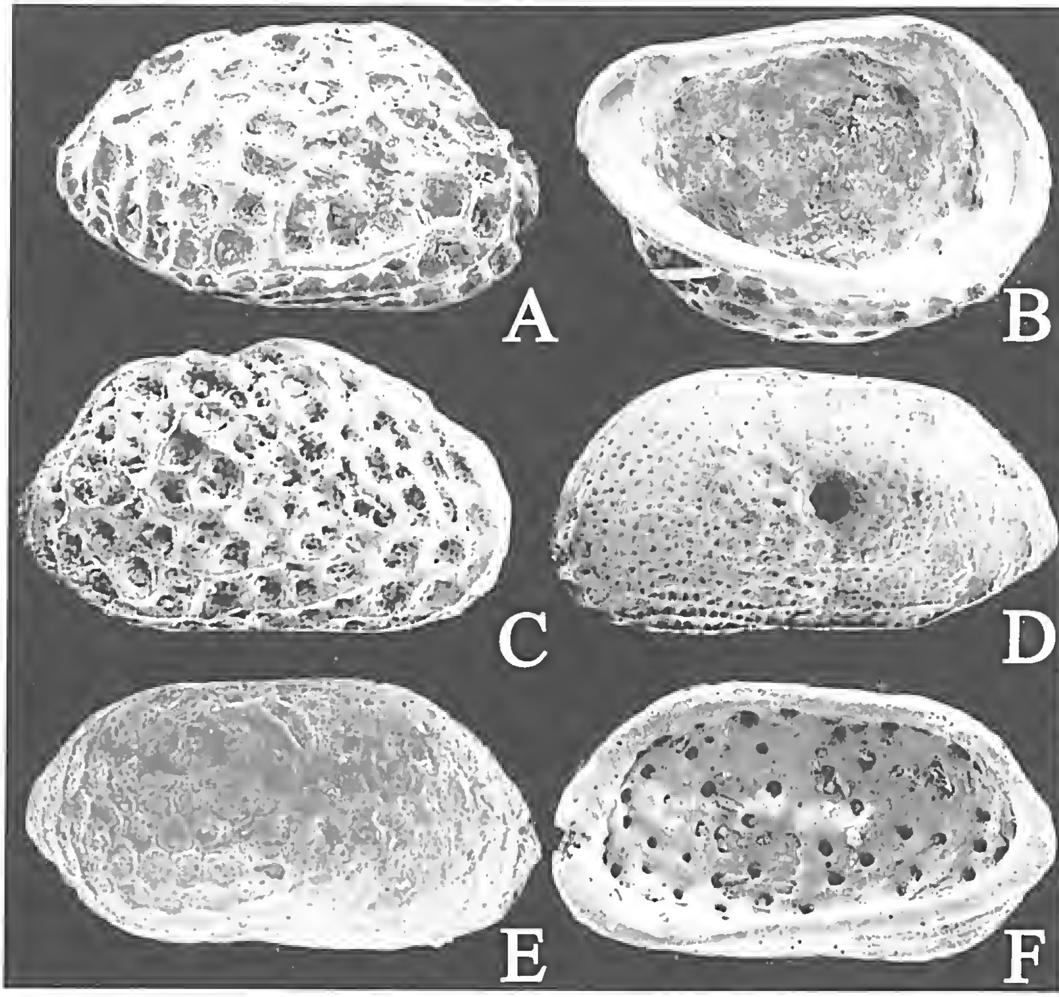

Fig. 1. A & B. *Loxocythere* (*Novoloxocythere*) *pelius* Warne. A. Holotype, right valve, female, external view, P122293, x118. B. Paratype, left valve, male, internal view, P311645, x118. C. *Loxocythere* (*Loxocythere*) *crassa* Hornibrook, right valve, external view, P312081, x174. *D. Loxocythere* (*Loxocythere*) *kingi* Hornibrook, left valve, external view, P311653, x172. E & F. *Loxocythere* (*Loxocythere*) *ouyenensis* (Chapman). Holotype, right valve, male?, P12529. E. external view, x119. F. internal view, x119. [Images as in Warne, 2004 a, b.]

Sars, and interestingly noted a possible affinity with the genus *Pelecocythere* Athersuch. Despite these diverse views, the interior margin shape, adductor muscle scars, and to a lesser extent, terminal hinge elements of the *Antarctiloxoconcha* type species *A. frigida* (see illustrations in Hartmann, 1989; plate 8, figs. 6 and 7), are very similar to the *Loxocythere* type species *L. crassa* (see Fig. 3C of this paper and Hartmann, 1982; plate 1, figs. 5 and 6). Hartmann, 1986 indicated that the soft part anatomy of the type species of *Antarctiloxoconcha* is consistent with the placement of this species in the Loxoconchidae. However, as noted by Athersuch and Horne, 1984, there is variance in opinions concerning the diagnosis of the family Loxoconchidae. As a consequence, and in spite of its name, the genus *Antarctiloxoconcha* is here considered to have a close morphological relationship to some genera of the family Cytheridae Baird. This broadly agrees with the original placement of *A. frigida* by Neale (1967) in the genus *Loxocythere*. Compared to the *Loxocythere* type species (*L. crassa* — Fig. 3 C-D), species of *Antarctiloxoconcha* are more rotund in external shape, have more subdued external ornament and posses a strongly crenulated and slightly arched medium hinge element (see Hartmann, 1989; plate

8, figs 4–7). Species here included in *Antarctiloxoconcha* have or had a Southern Ocean (coastal Antarctica & southern Australia) or south-west Atlantic Ocean (continental shelf) distribution.

REFERENCES

Athersuch, J. and Horne, D. J., 1984. A review of some European genera of the Family Loxoconchidae (Crustacea: Ostracoda). *Zoological Journal of The Linnean Society* 81: 1–22.

Hartmann, G., 1982. Beitrag zur Ostracodenfauna Neuseelands (mit einem Nachtrag zur Ostracodenfauna der Westküste Australiens). *Mitteilungen aus dem Hamburgischen zoologischen Museum und Institut* 79: 119–150.

Hartmann, G., 1986. Antarktische benthische Ostracoden I (Mit einer Tabelle der bislang aus der Antarktis bekannten Ostracoden). Auswertung der Fahrten der "Polarstern" Ant 111/2 (Sibex-Schnitte) und der Reise 68/1 der "Walther Herwig" (1. Teil: Elephant Island) in die Antarktis. *Mitteilungen aus dem Hamburgischen zoologischen Museum und Institut* 83: 147–221.

Hartmann, G., 1989. Antarktische benthische Ostracoden V. Auswertung der Südwinterreise von FS "Polarstern" (Ps9/V-1) im Bereich Elephant Island und der Antarktischen Halbinsel. *Mitteilungen aus dem Hamburgischen zoologischen Museum und Institut* 86: 231–288.

Keen, M.C., 1982, Intraspecific variation in Tertiary ostracods. In Bate, R.H., Robinson, E., Sheppard, L.M. (Eds.). *Fossil and Recent Ostracods*. Ellis Horwood Ltd, Chichester, U.K., 381–405.

Majoran, S., 1996. On *Schizocythere inexpecta* Mc Kenzie, Reyment and Reyment. *Stereo-Atlas of Ostracod Shells* 23(6): 21–24.

McKenzie, K. G., Reyment, R. A. & Reyment, E., 1993. Eocene Ostracoda from the Browns Creek Clays from Browns Creek and Castle Cove, Victoria, Australia. *Revista Española de Paleontología* 8(1): 75–116.

Neale, J. W., 1967. An ostracod fauna from Halley Bay, Coates Land, British Antarctic Territory. *British Antarctic Survey Scientific Reports* 58: 1–50.

Neil, J. V., 2000. A Recent ostracode assemblage from Erith Island, Bass Strait, southern Australia — geographical and ecological comparisons, with a description of a new species of *Rotundracythere* (Ostracoda: Crustacea). *Proceedings of the Royal Society of Victoria* 112(2): 119–132.

van den Bold, W.A., 1963. Upper Miocene and Pliocene Ostracoda of Trinidad. *Micropalaeontology* 9(4): 361–424.

Warne, M.T., 2004a. Description of *Loxocythere (Novoloxocythere) pelius* subgen. et sp. nov. (Ostracoda) from the Cenozoic of S.E. Australia with comments on species of *Antarctiloxoconcha*Hartmann, 1986 and *Loxoreticulatum* Benson, 1964 from Australian and Antarctic marine waters. *Proceedings of the Royal Society of Victoria* 116 (2): 233–2

Warne, M.T., 2004b. Observations on *Loxocythere* (*Loxocythere*) *onyenensis* (Chapman, 1914) (Ostracoda) from the Cenozoic of S.E. Australia with comments on species attributed to *Microcytherura* Müller, 1894 and *Hemiparvocythere* Hartmann, 1982 from Australian and New Zealand marine waters. *Proceedings of the Royal Society of Victoria* 116 (2): 243–250.

Whatley, R.C., Chadwick, J., Coxill, D.J. and Toy, N., 1988. The ostracod family Cytheruridae from the Antarctic and south west Atlantic. *Revista Española de Micropalaeontologia* 20: 171–203.

Whatley, R.C. and Cusminsky, G., 2002. Upper Pliocene Ostracoda from the Burdwood Bank, SW Atlantic. *Revista Española de Micropalaeontología* 34(1): 53–80.

Whatley, R.C., Moguilevsky, A., Ramos, M.I.F. and Coxill, D.J., 1998. Recent deep and shallow water Ostracoda from the Antarctic Peninsula and the Scotia Sea. *Revista Española de Micropalaeontología* 30(3): 111–135.

YVONNE AITKEN, AM, DAGR SC
FELLOW OF ROYAL SOCIETY OF VICTORIA:

17.10.1911–29.11.2004

Dr. Yvonne Aitken was a pioneer agricultural scientist and one of the earliest women graduates from the Faculty of Agricultural Science at The University of Melbourne. After obtaining her Master's degree, Professor Samuel Wadham appointed her as his research assistant. Her first task was to investigate what could be done to improve the poor rate of germination of subterranean clover seed. Ultimately she established that the seed germinated very successfully if carefully scarified before planting. This simple, cheap solution was of great assistance to the pastoral industry throughout Australia. In 1945, she was appointed as lecturer and retired as a reader in 1974 in the Faculty of Agricultural Science.

Yvonne was born in Horsham and in her early childhood lived in a number of different Victorian country towns. With a scholarship from St Arnaud she began a BAgrSc degree in 1930 and lived in Janet Clarke Hall, where she was later to be senior tutor and Vice Principal for 25 years and to be honoured as a Foundation Fellow of that College. Yvonne graduated in 1936 with Honours, despite having to convalesce from tuberculosis for two years mid-degree. After graduation she immediately began a MAgr Sc project studying the effect of length of day on the flowering behaviour of plants. This proved to be the start of a life-long love affair devoted to the reaction of field peas to climate and day length, culminating in a DAgr Sc in 1970 (the first woman to hold that degree in Victoria) and the publication of a definitive monograph, Flowering Time, Climate and Genetics (1974) and the text, Handbook of Flowering. In recognition of her contributions, she was elected a Fellow of the Institute of Agricultural Science.

I first knew Yvonne in 1943 when I was a BAgr Sc student in the second year of the course, then held at Dookie College in northern Victoria. Yvonne recruited me to monitor a patch of her precious peas — to record the dates at which flowers were produced and from which nodes, and when seeds were set. Yvonne had by then begun the most amazing collection of cultivars of field peas and other legumes from around the world from Alaska to Mexico and Peru, from Macquarie Island to Hawaii from Ethiopia to Greenland. These were meticulously collected and annotated and tested for their behaviour under Victorian conditions, particularly in the drier parts of north and central Victoria. When Yvonne began her work the cultivars of peas then available to include in rotations with cereals were not well suited to the short growing season in the north. Thanks to her work, a superior strain she called Derrimut is now widely used on Victorian farms.

Although her research was closely directed to legumes for farmers, she was interested in all forms of plant life and in our native flora. It is typical of the breadth of her interest in science that she became an associate member of The Royal Society of Victoria the year she graduated and became a full member in 1959. The Society elected her a Fellow in 2001 in recognition of her long and distinguished career and her association with the Society.

Whenever Dr. Aitken's name is mentioned, everyone remarks upon her unassuming demeanour and gentle relationship with her colleagues and the students in her care. Being congenitally untidy myself, I must say her office endeared her to me immediately — you could hardly see her for piles of papers, packets of seed, gumboots and her watercolours propped up against anything able to hold them halfway upright. She was particularly skilled in black and white photography as well as with watercolours. Her acutely honed powers of observations were applied as much to all of her contacts with people, as to the legumes she studied, and consequently she was a discerning support for students, particularly international ones coming to Australia from totally different cultural backgrounds. Her kindness and sympathy shone through.

While it is true to describe Yvonne Aitken as a researcher who devoted her entire life (long after official retirement) to science, she was always a humble, delightful, concerned person.

Prepared by Professor Nancy F. Millis

THE NEW DARK AGE OF SCIENCE: HOW INDEPENDENT THINKERS ARE AN ENDANGERED SPECIES

ADDRESS TO THE ROYAL SOCIETY OF VICTORIA, 10TH NOVEMBER 2005

KARINA KELLY

Presenter, *Catalyst*, ABC TV and Immediate Past-President, Royal Society of New South Wales

I will start tonight by declaring that I am not a scientist. I did study medieval history, economics, archaeology and English. What I have to say tonight will touch both on history and economics but mostly it comes as a result of my nearly twenty years of reporting science for the ABC.

As I'm sure you know, the Royal Society in Britain, on which our Royal Societies in the States of Australia are modelled, is one of the most influential scientific bodies in the world. It was the first society to be given Royal patronage which is why there is no other identifying name. This honour was bestowed by the newly restored monarch, Charles II in 1661. The Royal Society was based on the ideas of Sir Francis Bacon who became Lord Chancellor under King James I some fifty years earlier.

When he wasn't being Lord Chancellor, Bacon was an essayist. He argued eloquently for a major shift in the way science was done and seen to be done. He wrote about the 'new' science because he wished to distance it from the old science of Alchemy. The Alchemists wanted to change base metals into gold. Some wanted to create a tiny human like Tom Thumb, called an homunculus. These people, Bacon argued were not using observation and objectivity as the basis for their work. His ideas were part of the great push towards empirical science which led to a massive expansion of scientific endeavour and the blossoming of a new era of independent thought.

Bacon urged the 'new' scientists to think about their motives.

> "For men have entered into a desire of learning and knowledge, sometimes upon a natural curiosity and inquisitive appetite; sometimes to entertain their minds with variety and delight; sometimes for ornament and reputation; and sometimes to enable them to victory of wit and contradiction; and most times for lucre and profession; and seldom sincerely to give true account of their gift of reason to the benefit and use of men." [1]

Bacon knew that if science was working for our benefit, it would be an unstoppable power. Sadly, he paid the ultimate price for his belief in observational science. In March 1626, while driving near Highgate, Bacon decided to conduct an experiment on meat to see if reducing its temperature slowed down the meat's decay. So he bought a fowl and stuffed it with snow. But in the process, he caught a cold, developed bronchitis and died on April 9th.

We pay lip service to the sentiments of Bacon here at the beginning of the 21st Century — we have ethics committees and departments of History and Philosophy of Science but in reality how much do we really encourage independent thought and altruistic research?

As I will try to show tonight, science is not a philosophy but a tool. It can be turned to many tasks and it can be waylaid, sabotaged and completely misrepresented. Unless we remain vigilant, we could return to the era of Alchemy and a new Dark Age.

History reaffirms what seems obvious to all of us, that unless blessed with independent wealth, scientists have always needed support or patronage. For the great astronomer Galileo Galilei, it was Cosimo II, Grand Duke of Tuscany and his Medici family. For Sir William Herschel who discovered the planet Uranus, it was King George III of England. Those who make lasting contributions to our knowledge, can expect to be lauded. But what they do for the rest of humanity is far greater than what they do for themselves.

These days in Australia, the patronage comes largely from government coffers in the form of university and CSIRO support. Government support for research has been waning for nearly twenty years as the Australian government has tried, not very successfully to encourage Australian business to invest in Research and Development.

This stems from the almost religious belief of this government and many others that the best way to organise everything is to let the market decide. So, instead of supporting the CSIRO and Universities

with government grants paid for by taxes, we give the most generous tax concessions in the world for businesses to claim their research.

I will return to this subject of how we support scientific research later, but let's examine how we got to the point of considering that private research is to be encouraged at the expense of publicly funded research.

Charles Darwin's Theory of Evolution brought with it certain unexpected side-effects.

One was something called 'social Darwinism'. In Darwin's time the argument raged about how best to organise society. What worked best and how could most people benefit? At this stage in European history people believed that it was necessary to strive for an improvement in social organisation. These days we hear very little of that concept. It has been demolished along with the Berlin wall.

What has replaced the outdated socialist ideal is social Darwinism. We don't just apply 'the survival of the fittest' to the jungle, we claim that society itself is a jungle and that we must all fight to survive, eat or be eaten. We no longer hear our leaders talk about how those less fortunate than ourselves should be looked after.

Indeed in Australia today we are more interested in locking them up. The prison population in Australia in only the ten years between 1990 and 2000 increased by a staggering 52% and those seven and a half thousand extra prisoners are costing us about 370 million dollars a year to entertain at her Majesty's pleasure, and the Australian taxpayer's cost.

What has this to do with independent thought? Throughout this period of enthusiastic incarceration, there has been no increase in serious crime. The homicide rate per hundred thousand people in 1915 was 1.8. In 1998 it was 1.6. There seems to be no logic to what we have done. It's as though all rational thought and analysis has been swept away by a wave of fear and emotion.

But back to social Darwinism. In a hundred years, we've gone from trying to improve society in various ways, to deciding that it cannot be improved. That no matter what happens people will always act out of self interest and the best policy is simply to let them get on with it.

Yet there is evidence that this is not so.

Many of you will have heard of the "Prisoners Dilemma", the most famous game in the mathematical discipline called Game Theory. Its all about lying and cheating versus co-operation and the calculations that go on in our heads about which is the best tactic. Life would certainly be a lot simpler, if everyone told the truth all the time. But we learn sooner or later that this is not so.

The prisoner's dilemma applies wherever there is a conflict between self-interest and the common good. The classic scenario goes like this. Two prisoners are held on charges of a crime they are accused of having committed together. Each prisoner has two choices — either testifying against the other (and so reducing his own sentence) or keeping his mouth shut. If he says nothing — one of two things will happen to him, depending on what the other prisoner does. If his fellow prisoner also keeps quiet, both of them would be convicted on a lesser charge or set free due to lack of evidence (and this is the best outcome for the two of them). If he says nothing and the other prisoner 'defects', and pins the crime on him, then he will have been cheated and end up worse off, serving a longer sentence for the crime. But if he 'defects' and tells the tale on his partner, then he can ensure that the worst scenario doesn't happen to him. In most cases, the argument goes, people defect because they don't believe that the other person is to be trusted.

This cheery little branch of mathematics was created in the middle of last century and one of its practitioners was John Nash, the Princeton mathematician who won a Nobel Prize in Economics for it in 1994, but perhaps more famously was portrayed by Russell Crowe in the Hollywood film, *A Beautiful Mind*.

Cornell University Professor, Robert Frank conducted a series of human experiments to further explore the Prisoner's Dilemma. He wanted to know if all people made the assumption that the other person is not to be trusted. Was this human nature or was it cultural? What he found was indeed enlightening. Using the resource closest to him, the University's students, he put students from different disciplines through the tests. Were the proportion of cynics and altruists the same? They were not. Economics students, indoctrinated with modern economic theory were much more likely to defect than astronomy students.[2] It seems that if you believe that "greed is good" and people are bad — it becomes a self-fulfilling prophecy.

The economic rationalists would have us believe that altruism is good, but it isn't how the world works. People, they say are basically selfish. But what if that proposition is not true? What does telling people it is true do to them? Matt Ridley in his *The Origins of Virtue* writes,

> "If people are not rational maximizers of self-interest, then to teach them that such behaviour would be logical is to corrupt them"[3]

This concept that people always act out of self interest is patently not true. We can walk down the street anywhere in the world and know that it is extremely unlikely someone will kill and eat us. If they do of course our story will be readily featured on the television news and splashed gorily on the front pages of the tabloid press. The truth is, human beings are very good at co-operation and at trust. It is what allows us to live in the giant hives we call cities. We deal with complete strangers every day. And for the most part we can assume basic patterns of reciprocal behaviour.

Of course it is in our best interests to trust others and for them to trust us. Otherwise we end up with social chaos. We would spend so much time protecting our children, food supply and houses from others that we would be unable to do anything else.

In his book *Trust* economist Francis Fukuyama makes the point that the economic success of different countries depends to a large degree on the history and culture of that country. In other words what works in one country may not in another. For example, France has a history of centralised control (both before and after the revolution) so adopting a uniform nuclear power policy across the country is easy but promoting a talented youngster above others who have been there longer is hard. Fukuyama doesn't write about Australia in his book. But he does write

> "As Adam Smith well understood, economic life is deeply embedded in social life, and it cannot be understood apart from the customs, morals, and habits of the society in which it occurs. In short, it cannot be divorced from culture."[4]

So the economic life of Australia is also embedded in its culture. And the culture of support for scientific research in this country has traditionally been from government sources. It's been that way for a hundred years.

This government and the previous Labor government have both made enormous efforts to follow in the footsteps of US enterprise and get Australian companies to invest in Research and Development. They have had limited success.

These things are worked out as a percentage of GDP or Gross Domestic Product so that countries with different sized economies can be compared.

The United States and Australian governments both spend about the same percentage of GDP (just under 0.75%) in government funded research. But business funding of Research in Australia is about the same as government, whereas in the US it's well over twice that. That's despite the fact that we have the most generous tax concessions for business research and development in the world. Most countries offer 100% tax deductions. Our government offers 125% and as much as 175% if the commitment continues over three years.

The OECD average of percentage expenditure on R&D is 2.25%. Australia is on 1.53% which makes us second bottom. But the crucial question is are we improving? [The answer seems to be 'no'.] The annual growth rate of expenditure on R&D and Singapore's investment is growing four times faster than ours and that's from a substantially higher base. But it's not just Singapore, it's Finland, Ireland, Sweden, Korea, Denmark, Taiwan and Canada that are increasing their expenditure on R&D faster than we are.

We have tried for the last twenty years to get business to invest in R&D without much success. Why? It's a difficult question but the business community also has a culture in this country. Changing it will not be something done overnight. In the meantime, I would argue that to cut funding to government bodies with proud records in research is not going to prepare us for the coming century. It is not going to make us competitive with the emerging economic powers of Asia which are putting money into research.

What has been the impact on publicly funded research in this country?

Well it's a bit hard to know where to start. You probably read last week that CSIRO is about to cut 200 staff in order to save about $5 Million dollars. They are in deficit a further 14.5 Million. While 5 Million dollars is not chicken feed, it is one eleventh the amount spent by the Federal Government on advertising the Coalition's proposed industrial relations legislation.

These cuts have been made over many years because of a sincerely held belief by those doing the cutting that government funded organisations are inefficient, unwieldy and slow to react to changing circumstances. This is often the case. I don't think anyone would disagree that large publicly funded organisations have many faults.

But they are also the organisations which have traditionally done the long-term thinking for us. More importantly, they simply do things differently from private companies. They are not there to make profits. They are there to serve the community.

In the case of the ABC, it has always made programs that Australians need to see as well as those they want to. Our funding is in such crisis that we cannot make more than a few hours of drama in a year. That's down from more than a hundred only a

few years ago. I hasten to add that this information comes from the newspaper. I'd tell you more about how difficult things are at the ABC but my contract does not allow me to speak publicly about the internal business of the ABC. I'm not sure if I'm allowed to speak publicly about how I'm not allowed to speak publicly. I'd better check that.

But back to the CSIRO. Research which attracts commercial partners is supported and that which doesn't is not. There's another way in which the CSIRO is becoming more commercially minded. According to this year's annual report the remuneration to board members of the CSIRO has increased by 50% in one year.

They also have a mission statement (although they don't call it one), they call it CSIRO's Purpose

It is

"By igniting the creative spirit of our people, we deliver great science and innovative solutions for industry, society and the environment."

Industry, society and the environment. In that order?

I thought I'd see what the ABC's annual report said. Funnily enough our mission statement doesn't say anything about creativity. I suppose that might imply we were making things up. No, our mission statement says

"Guided by the ABC Charter to engage our audiences with an independent, distinctive and appealing mix of programming and content...."

Which does conveniently get us back to independence. Independence is truly something to be valued and as we commercialise government bodies we lose it. The reason I am still at the ABC after nearly 20 years is because at our best we still choose our subject matter on the basis of its importance to the Australian community.

Reality television programs that exploit people's unhappy lives for entertainment are indeed the ultimate example of social Darwinism. This voyeurism and titillation is what most people want to watch. Is that enough of a justification for them? It is, after all, what the market has decided to give us.

And when we are not watching someone spread with honey and tied to an ant nest, we might like to watch the dramas unfolding on the television news. Hurricane Katrina, Australia's drought, the Antarctic Ice shelves melting.

Is it caused by global warming? Who will we ask to tell us the truth? Not those whose research funding is reliant on companies that burn or mine fossil fuels.

The challenge we face from global warming is indeed a daunting one. Australia has always been a difficult place to survive. When I read the Piggott report before taking up a position as a council member of the National Museum of Australia, I was moved by how definitive this relationship between Australians and the Australian environment really is. Whether you imagine the experiences of the Soldier Settlers' struggle to make the best of sometimes unviable farmland, or of the first Australians, who learned to keep up complex kinship connections to be able to leave drought-stricken areas for those more fertile, it is our struggle to survive in this unpredictable climate that defines the Australian character. We do not have the luxury of predictable rainfall, as they do in North America and Europe. What's more, the climate modellers think that global warming will make the northern hemisphere hotter and wetter and the southern hemisphere hotter and dryer. If they are right, Australia will play the role of coal mine canary for the rest of the world.

Either way, it seems that we have many rapid changes ahead of us. How we prepare for these changes is crucial. We need to be able to respond to problems (or challenges as it's now fashionable to call them) with clarity, our advice needs to be credible and unbiased (it needs to be independent) and we must all get better at understanding complex problems.

An educated (and sceptical) population will best be able to weigh up (and occasionally reject) what our tabloid press and politicians are telling us. Now, more than at any other time in history we need people to be analytical and logical, not swept away by the emotions of the moment.

We are told that we live in dangerous times. People are in constant fear of being attacked by terrorists, of their children being attacked by paedophiles. They sue a company because they have dropped a hot coffee on their lap.

Coffee's dangerous, you know!

Yet, a recent report on global trends in political violence by Australian Andrew Mack, who is director of the Human Security Centre in Vancouver says that "there are fewer wars than there used to be and they are becoming less deadly." He says the casualties from terrorist acts are minimal and do not warrant the current wide-spread concern among the public.[5]

Apparently the most severe conflicts — those with more than 1000 casualties a year declined by 80% in the 1990's. The number of armed conflicts has declined by more than 40% in the same time and battle

casualties have dropped almost unbelievably — from an average of 38 thousand in 1950 to 600 in 2002.

And if that hasn't made you relax, perhaps Tuesday's roundup of terror suspects did. No?

When in history would you prefer to live? Just take the 20th Century — well there was the First World War and the Spanish flu pandemic — that killed maybe 50 million people. Then, ten years later there was the Wall street collapse and the great depression which segued rather quickly into the Second World War and after that there was the Cold War and the constant threat of the Earth being blown up in a nuclear conflagration. Then there was Korea and Vietnam. Maybe it was pretty good from '72 when we pulled out of Vietnam until '83 when the AIDS epidemic hit. Maybe the good old days weren't quite that good.

The truth is we've never been safer than we are right now and we've never been more nervous about our safety.

On the other hand, reading Tim Flannery's *The Weather Makers*[6] and Jared Diamond's *Collapse*[7] should be making us very nervous. There is much convincing scientific evidence that global warming is happening now and that we may already have to live with the dramatic consequences of permanently changed weather patterns and sea-level rises.

Independent thought is required to be able to sift the hype from the truly important political questions of our time.

For decades it's been difficult because there have been so many conflicting reports. The satellite data didn't match the ground based data, were the effects being masked by global dimming, was this global warming stuff all nonsense anyway?

Now, the information coming in is ominous. The seas are warming. Ice shelves are melting and yet the political resolve to do something about such a momentous problem is so far not there. We are lucky that this challenge has coincided with our burgeoning computer power for it is this which just might save us. I have watched as scientists have taken on calculations of such complexity that they would have made Darwin or Wallace gasp. Yet we can and are adding more and more of the minute details to the environmental balance sheet to be able to truly predict what may happen to the world's climate.

So how are we doing? Well, at the end of March, we got a report card.

Called the "Millennium Ecosystem Assessment" it was commissioned by the United Nations in 2000 to look at the future of the world's natural assets and human well-being. This is not the ramblings of a band of lefty tree huggers. It involved the work of 1,360 experts from 95 countries and has been scrutinized by governments and independent scientists. It's basically an audit of our natural assets and what's happened to them in the last fifty years or so. Here's one of the sober statements from the board.

> "At the heart of this assessment is a stark warning. Human activity is putting such strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted."

Here are some of the numbers.

* Water withdrawals from rivers and lakes for irrigation, household and industrial use doubled in the last 40 years.
* In some regions such as the Middle East and North Africa, humans use 120% of renewable water supplies (due to the reliance on groundwater that is not recharged).
* More land was converted to cropland since 1945 than in the eighteenth and nineteenth centuries combined, and now approximately one quarter (24%) of Earth's terrestrial surface has been transformed to cultivated systems.
* Since 1980 approximately 35% of mangroves have been lost, while 20% of the world's coral reefs have been destroyed and a further 20% badly degraded or destroyed.
* At least one quarter of marine fish stocks are overharvested.
* In some areas, the total weight of fish available to be captured is less than a hundredth of that caught before the onset of industrial fishing.

The authors include Lord Robert May, formerly a professor of Physics at the University of Sydney who went on to work on Chaos theory and ecosystems in the department of Zoology at the University of Oxford, then became Chief Scientist in Britain and has just retired after seven years as the President of the Royal Society of London.

Here's what the authors say.

> "Although the evidence remains incomplete, there is enough for the experts to warn that the ongoing degradation... is increasing the likelihood of potentially abrupt changes that will seriously affects human well-being. This includes the emergence of new diseases, sudden changes in water quality, creation of 'dead zones' along the coasts, the collapse of fisheries, and shifts in regional climate."[8]

Against this backdrop, we have the influence of post-modernism on science. The idea that there is not one, but many voices is a good way to tell stories and to study history. In fact, different viewpoints is what history is all about.

But science has been undermined by the concept of 'many voices' by those who simply don't understand how science works or what it is. The term 'western' is added to science as if to say that 'non western' science is somehow different. Into this atmosphere has come the force of Intelligent Design. The advocates of ID are pushing so hard to get it taught as science in US schools because religion is not taught in state schools in America. If they don't get ID into schools as science, they don't get it into schools at all. So, a great deal of money has been spent on a very glossy DVD with excellent animation to show the complex workings of tiny single celled organisms.

These are simply too complex to be explained (and so God did it). What's wrong with this argument? It doesn't explain anything — of course. When we look at Mount Rushmore or the hieroglyphics of the ancient Egyptians, their argument goes, we are able to recognise them, not as random acts of nature but as the work of someone intelligent. So you get the logic? Mount Rushmore is complex — it's made by an intelligence, the flagellum of a bacterium is complex it must also be the work of an intelligence. I'm no logician but I think that's the same as saying 'a dog has four legs, a cat has four legs therefore a dog is a cat."

I don't need to tell this audience that that the purpose of science is to understand the world a little better. It is certainly not the role of science to say 'it's too complex for us to understand and so we won't try to.' Attacks on science come in many forms. There's the subtle undermining that comes from years of toothpaste and washing powder commercials with people in white lab coats and horn-rimmed spectacles.

Then there are the broadsides from the advocates of Intelligent Design who would like to diminish the status of science which they rightly see as one of the foundations of the modern western world. Why? because they are frustrated with our materialism and lack of ethics and they blame science for what we have become. In essence they blame science for Social Darwinism.

They are aided by unscrupulous scientists who 'take the money' and argue far longer than they should that 'smoking doesn't damage your health' or that there is no evidence that human activities are changing the earth's climate.

But science is not a philosophy or religion. It is a tool and we must apply our own values and set our own goals when we use it. Applied well, science will help us understand what's happening to our climate, help us tackle a bird flu outbreak if it occurs. It is science can provide us with alternatives to burning fossil fuels. But we have to decide that those are our priorities. Science can't do that for us and neither can the free market.

It is for this reason that we must re-build publicly funded science. We need thinkers that are paid to see the world differently from the rest of us. They should be securely employed (and properly paid) and they should feel able to speak about their findings without fear that they will offend the government of the day or powerful business interests. If we don't find money in our taxes for these people, our society will be impoverished in the midst of all our wealth.

Are we headed for another dark age? Quite possibly. If superstition is allowed to flourish and if too many of us allow ourselves to be frightened by non-existent threats while we ignore the genuine ones.

As Jared Diamond so eloquently argues in his book Collapse, human beings have shown themselves capable of destroying their habitat many times over. The challenge for the six billion people on earth right now is not to let it happen on a global scale and forever.

I'll leave the final word to Francis Bacon on whose ideas the Royal Society was founded.

> "Lastly I would address one general admonition to all; that they consider what are the true ends of knowledge, and that they seek it not wither for pleasure of the mind, or power or any of these inferior things; but for the benefit and use of life; and that they perfect and govern it in charity."[9]

1 "The Advancement of Learning" Book 1, Works 3: 294, 2 *Passions Within Reason*, Frank, RH, Norton NY, 1988, 3 *The Origins of Virtue*, Matt Ridley, Viking, 1996, page 145, 4 *Trust*, Francis Fukuyama, The Free Press, 1995, page 13, 5 Sydney Morning Herald 21 October 2005, page 2, 6 *The Weather Makers*, Tim Flannery, Text 2005, 7 *Collapse*, Jared Diamond, Viking Penguin, 2005, 8 From http://www.millenniumassessment.org/en/index.aspx News Updates "Experts Warn Ecosystem Changes Will Continue to Worsen, Putting Global Development Goals at Risk. Wednesday March 30, 2005, 9 *Magna Instauratio*, preface, Works, 4: 20–21.

DR ELIZABETH ARNOLD RIPPER 1909–2004: EARLY 20TH CENTURY VICTORIAN PALAEONTOLOGIST IN MEMORIAM

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TURNER, S., 2005:12:31. Dr Elizabeth Arnold Ripper 1909–2004: early 20th century Victorian palaeontologist. In Memoriam. *Proceedings of the Royal Society of Victoria* 117(2): xlix–liv. ISSN 0035-9211.

Australian Elizabeth 'Betty' Ripper, geology student at the University of Melbourne in the late 1920s to early 1930s recently died in Britain. She did pioneer work Australian in invertebrate palaeontology with work on Palaeozoic graptolites and stromatoporoids, gaining her Ph.D. at Cambridge University in 1936. Nine of her stromatoporoid taxa remain valid and two taxa bear her name. Unable to gain employment after returning to Australia in the mid-1930s and then after marriage in Britain she was not able to pursue further her vocation.

ELIZABETH 'Betty' Ripper was born on the 7th September 1909, in Melbourne. She was educated at Melbourne High School from 1925 to 1927, which was co-educational until 1927 when boys moved to a new school in South Yarra. It was there that she first encountered geology in 1925. Fortuitously, through a confusion in the timetables, having attended a few classes under the "attractive" teaching of geography and geology master, J. Sidney Kitson, Betty became really hooked. Her family was dubious about this choice of subject when she said she wanted to study geology further, as her intended career was, they thought, to be in languages, but she refused to be dislodged from her intention. In her schooldays Betty became interested in the Victorian goldfields collections in the Geological Museum of the Victorian Department of Mines (this museum was in a building in Macarthur Street, now demolished — see photograph in Birch, 2003, fig. 25.13, p. 679).

Photograph of Dr Elizabeth Ripper in 1993 (courtesy of Barry Webby).

Betty went on to take Geology at the University of Melbourne for her undergraduate degree from 1928 to 1931. There followed a year as Kernot and Wyselaskie Scholar in Geology gaining her M.Sc. in 1932 (William Charles Kernot was Lecturer in Engineering, University of Melbourne, 1868–82 and Professor 1883–1909, President of the Royal Society of Victoria 1885–1900; John Dickson Wyselaskie belonged to a family of wealthy Western District graziers). At that time there were two women in the Geology Department, Bertha Keartland (demonstrator, Kelly 1993) and Kathleen McInerny (Sherrard after marriage, e.g., Darragh et al. 1976, Kelly 1993, who had been appointed Assistant Lecturer in 1920, Summers 1947), providing rare role models. Fellow Melbournian McInerny, the first woman graduate in geology at the University of Melbourne in 1918, took her M.Sc. in 1921 and wrote several papers on graptolites (D.F.B. 1975). Betty related (in litt. to S. Turner, 1994):

"In our student days we found (the) GA and G(eol). Soc. (Lond.) Presidential Addresses

most useful for overviews of particular skills or groups — usually, as you would know, the culmination of a lifetime's work."

The Melbourne University Geology Department under Professor Ernest W. Skeats (1875–1953) and Associate Professor Herbert H. Summers (1876–1963) was strongly petrologically based, but the important palaeontological influence at that time came from Frederick A. Singleton (1897–1947, Summers 1947), who was greatly interested in Tertiary Mollusca and Foraminifera. One contemporary of Betty's, Professor Edwin Sherbon Hills (e.g., Sherratt & McCarthy 1992) took part in and briefly documented the geology field trips led by Skeats and Singleton (Fig. 1 A-C). Such field excursions, sometimes long weekends, went for example, to Colac for Western District basalts; Daylesford for the Silurian, San Remo and Wonthragi for Jurassic coal measures, as well as day excursions, which took place on Saturdays:

"We had problems, on coming of age, re getting back in time to vote! On one hair raising occasion, in a definitely undermapped area in Bacchus Marsh, the party got lost among the meanders of the Herderderg R. and some (not including me, fortunately) did not make it to civilisation until the next day! We seemed to be tramping for miles along a very rocky river bed, with much damage to our boots. This was in 1933 and was duly reported in the newspapers. It was recognised then that geologists intending fieldwork would often need to cope in hitherto unmapped territory and the M.Sc. year included a course of fairly basic surveying that we shared with future engineers and architects. Where to put railways, roads and plane tabling around the streets of Carlton, Melbourne N3!" (in litt. to S. Turner, 1994). Geology students in the same era included a high proportion of women (also seen in photographs in the Sherbon Hills Archive at NLA, Sherratt & McCarthy 1992): Anne Nicholls; Ray Suding; G. Baker; Austin Edwards; P. Moffatt; M. C. Clayton; F. Keogh; G. Phillips; F. White; Rex Southey; R. Williams; F. Casey; Ned Madden; Stella Byrne; Jo Anderson; George Edwards; Moira Pye; Beryl Christie; Mysie Jensen; Coralie Skinner and David Thomas.

Her initial researches were on Ordovician and Silurian graptolites but she also wrote on Silurian (Lilydale Limestone) stromatoporoids for her M.Sc. The latter was published in 1933 in the Proceedings of the Royal Society of Victoria, the main geological forum in the State, which she had joined as an Associate when a student in 1930. During her thesis work Frederick Chapman (1864–1944) at the National Museum of Victoria was her mentor. Betty prepared rocks and made thin sections as well as her own drawings, erecting then four new taxa, one named for Chapman. As a research student Betty began to take part in the scientific scene and attended the 1932 meeting of the Australasian Association for the Advancement of Science in Sydney. In 1933, her professors and mentors advised a course of graptolite study under Dr Gertrude Lillian Elles (1872–1960) at the Sedgwick Museum, Cambridge University (part of the Department of Earth Sciences). She took with her to Britain Victorian material from various collections. In the meantime she also had made a collection of stromatoporoids, mainly from the Devonian limestones of Lilydale and Buchan, in central and eastern Victoria, respectively. She was advised, fortunately as it turned out, to continue work on those, with additions from other collections.

Arriving in Cambridge University in the autumn term of 1933, she was enrolled as an 'anti student' (i.e. non-resident student) of Newnham College, where Elles was a Director of Studies. Betty reminisced (in litt. to S. Turner, 1994) "Gertrude L. Elles was approaching the end of her career and had done her major work on British graptolites, and in me took a kindly if rather impersonal interest as my supervisor, and of stromatoporoids she worried hardly a jot, so with those I was more or less in the same situation and well and truly on my own! at least as

Fig. 1A-C. Betty Ripper with fellow students from Melbourne University Geology Department in the late 1920s to early 1930s. From Edwin Sherbon Hills (ESH) archive (Sherratt & McCarthy 1992). Black and white photographs, NLA MS8564 17/11, late 1920s geology field trips in Victoria. Most are labelled by ESH with locations, names and other comments: A, NLA MS8564 17/11.1, 1929, off Korkuperimul Creek, Victoria: Those pictured include staff: Professor E. W. Skeats; F. A. Singleton and students; Betty lying down in middle, hand over head; B, NLA MS8564 17/11.2 1929 off Korkuperimul Creek, Victoria: students, caption on back of this photo provides names: Anne Nicholls, Ray Suding, second from the left in side view, Betty Ripper (misinterpreted in Sherratt & McCarthy 1992 as "Riffer"), G. Baker, E. S. Hills, ...Jackson, Austin Edwards; C, NLA MS8564 17/11.3, Betty and another female student (Anne Nicholls?): caption written by ESH on reverse reads: "Geological research in the Maldon district January 1931. Unfortunately you can see the piece of string which worked the oracle. Betty got sunburned on the eyelids every day up there!". Copyright held and copies made by permission of the National Library of Australia.

regards the Australian faunas. At that stage the work was mainly straightforward description of species and did not lend itself to any startling discoveries. Most of the graptolite and stromatoporoid material was collected by myself, with additions from other collections; looking back, I must confess to some amazement that I was allowed to wander about the countryside alone". Other mentors were graptolite worker. Dr Oliver M. B. Bulman (1902–1974), and museum curator A. G. Brighton, whose main interest was in Cretaceous echinoids.

The Sedgwick Museum in the thirties was frequented by many interesting personalities. Betty particularly remembered later in life (in litt. to S. Turner. 1994) noted explorers such as Noel E. Odell (British glaciologist, geographer and "a tall strong splendidly-built man, easy and popular, and a graceful and experienced climber with a great record in the European Alp" — H.J. Harrington, pers. comm. Oct. 2004) and Antarctic explorer, Vivian Fuchs, often encountered in the attic where the young researchers had little cubby-holes separated by improvised walls of packing cases, files, microscope boxes etc. etc. Her immediate neighbor was young Dorothy Hill, working on the Palaeozoic corals that were the subject of her Ph.D. and later led to the award of her F.R.S. She was also working under Elles and Bulman (Campbell & Jell 1998). She and 'Dotty' were quite "buddies" in the Sedgwick, and even had a rather hairy field trip together in Wales! The toughening-up she had had under Professor Skeats stood her in good stead not only in route marching, but in contending with mid-winter rain and gales as well. While in Cambridge, she joined the Sedgwick Club, which ran excursions in the vacations.

She soon discovered that most of the interesting work on graptolites seemed to have been done on much better preserved material and that her material would probably have very little to contribute. The stromatoporoids, however, saved her day and her (research) life. In her paper (1937b), she acknowledges Drs W. D. Lang and H. Deighton Thomas of the British Museum (Natural History) in London for permission to work on the Nicholson collection. Betty had a happy time making great quantities of thin sections and also spent some time with Deighton Thomas being allowed to slice some of their specimens, as well as some from the Sedgwick Museum, a freedom of access and facilities that Betty thought later in life (pers. comm. to S. Turner 1994) would not be so easily available today. She was keen to bring back British material to Australia for direct comparison and was able to deposit some of her own in exchange while in Cambridge.

"I had the loan of a petro(logical) microscope at the Sedgwick and of course free run of the dungeon where with the help of the current lab. assistants, Albert and Arthur, I cut millions of their sections. I quite enjoyed this "trained ape work" (I got this lovely expression from a field man in BGS sent on a collecting expedition to B. Solomon Is.), as it gave me time to think about what to put in my thesis!" (in litt. to S. Turner 1994).

After three happy years in Cambridge, as she related (in litt. 1994) Betty took full advantage of all the cultural opportunities, immersing in music and theatre. She was granted her Ph.D. in 1936. Before she returned to Melbourne to split up the thesis into papers of a length suitable for publication in the Proceedings of the Royal Society of Victoria she donated stromatoporoid material including figured specimens to the Sedgwick Museum, Cambridge, and to the British Museum of Natural History, London (Cleevely 1983). From 1932–1938 there were two papers on Ordovician graptolites and five on Victorian stromatoporoids from Devonian limestones, as well as another small paper on *Amphipora* from Western Australia. This small body of work was her contribution to Australian geology and palaeontology and it has proved a useful one over the years, especially her pioneer studies of the Victorian Lower Devonian stromatoporoid assemblages (see Webby *et al.* 1993). Devonian *stromatoporoids Pseudotrupetostroma ripperae* Webby & Zhen 1993 from the Jesse Limestone of New South Wales and *Hermatostromella holmesae* (Webby, Stearn & Zhen 1993) from the Lilydale Limestone of Victoria have been named in her honour — the latter based on her married name. The fact that virtually all the species (and subspecies) she first named in her 1933, 1937a and 1937c papers were retained as valid by Webby *et al.* (1993) in their recent revision of the faunas is testimony to the high quality of her pioneering taxonomic studies. These taxa are: *Actinostroma compactum* Ripper 1933, *Atelodictyon chapmani* (Ripper 1933), *Atopostroma distans* (Ripper 1933), *Petridiostroma delicatulum* (Ripper 1937c), *Plectostroma altum* (Ripper 1933), *Pseudotrupetostroma buchanense* (Ripper 1937c), *Salairella lilydalensis* (Ripper 1937a), *Schistodictyon? cylindricum* (Ripper 1933), and *Tubuliporella calamosa* (Ripper 1933).

In 1937, Betty returned to Britain to marry Stanley C.H. Holmes (Trinity Coll. Cambridge) then of the Geological Survey (G.B.), whom she had met at

the Sedgwick Museum. From then on her opportunities for further research narrowed as she found living conditions in suburban London were not conducive. Soon thereafter came World War II and family (two sons, neither of whom became a geologist). She joined the Geologists' Association, and although not a Fellow, had contact through her husband with the Geological Society of London, and quite often attended their meetings.

Kelly (1993) has looked at the early women science students at the University of Melbourne. She and Turner (1998) have noted that most women were unable to get paid work in their fields of interest, many becoming teachers and promoting science including geology to the next generation of girls. In the mid-1930s when the Depression limited possibilities there were few professional palaeontologists in Australia. Two women already had coveted places in Melbourne with Irene Crespin as Commonwealth Palaeontologist based at the museum and Isabel Cookson in the university. In 1994 Betty Ripper on considering her own life mused,

> "If I had remained in Melbourne, I may have found a palaeontological niche in the National Museum of Victoria working under R.A. Keble. Even now, with much wider acceptance of women in spheres outside the home, it is difficult without very substantial resources of money and minions to reconcile career, marriage and (especially) family."

For her, a longer career was not to be. She maintained her interest in geology, however. With Barry Webby and other workers she exchanged Christmas cards and messages for a number of years post 1993, and he sent her stromatoporoid papers of interest (B. Webby, pers. comm. 2004). In 1999 Colin Stearn, Barry Webby, Heldur Nestor and Carl Stock published a revision of the classification and terminology of Palaeozoic stromatoporoids. She wrote shortly after in 2000 thanking Barry for her copy, and adding the following remarks:

> "Everything one could possibly desire to know — & things have moved on more than somewhat since my days (now v. remote!) of concern with ancient coral reef faunas. It has been quite a revision course, seeing so many of the old familiar names — genera and people! — & now so many new genera. You and your 3 colleagues must have had a nightmare checking all the info, & references, not to mention the onerous task of proof-reading.
>
> It was a pleasure to see such a beautifully produced monograph — those places on cultural fault-lines seem to be able to produce miracles!"

[B. Webby pers. comm. to S. Turner, Oct. 2004].

Betty Arnold Holmes died just short of her 95th birthday in June 2004 after a short illness, at her home in Ewell, Epsom, Surrey.

ARCHIVAL MATERIAL

Museum of Victoria: Melbourne University file labelled "Catalogue of E. A. Ripper Collection of Australian, British & foreign stromatoporoids and graptolites" (originally presented to the University in 1936). The file contains some drawings of British graptolites by Betty Ripper. Victorian stromatoporoid material, and graptolites collected by her by locality, as her M.Sc. study was not published.

National Library of Australia (NLA): Edwin Sherbon Hills archive (Sherratt & McCarthy 1992). Black and white photographs from NLA MS8564 17/11.

Dr Susan Turner, Dr Barry Webby, Mr Michael Holmes: personal and other correspondence.

BIBLIOGRAPHY FOR DR E.A. RIPPER

Ripper, E. A., 1932. The distribution of the Zones of the Castlemaine and Darriwil Series near Ingliston. *Proceedings of the Royal Society of Victoria* 44: 200–211, pl. xx + 1 text-fig.

Ripper, E. A., 1933. The stromatoporoids of the Lilydale Limestone. Part I. Actinostroma and Clathrodictyon. *Proceedings of the Royal Society of Victoria* 45: 152–164, 6 text-figs.

Ripper, E. A., 1936. Some Victorian graptolite and stromatoporoid faunas. *Dissertations of the University of Cambridge* 1935–36, Abstract: 68–69.

Ripper, E. A., 1937a. A note on the occurrence of *Didymograptus protobifidus* Elles in the Lower Ordovician of Victoria. *Proceedings of the Royal Society of Victoria* 49: 153–164, 9 figs.

Ripper, E. A., 1937b. The stromatoporoids of the Lilydale Limestone. Part II. *Syringostroma*, *Stromatopora* and other Genera. *Proceedings of the Royal Society of Victoria* 49: 178–205, 2 pls, 4 figs.

RIPPER, E. A., 1937c. On some stromatoporoids from Griffith's Quarry, Loyola, Victoria. *Proceedings of the Royal Society of Victoria* 50: 1–8 + 1 pl.

RIPPER, E. A., 1937d. On the stromatoporoids of the Buchan District, Victoria. *Proceedings of the Royal Society of Victoria* 50: 11–45, 4 pls.

RIPPER, E. A., 1937e. A note on the occurrence of *Amphipora ramosa* (Phillips) in Western Australia. *Journal of the Royal Society of Western Australia* 23: 37–41.

RIPPER, E. A., 1938. Notes of the Middle Palaeozoic stromatoporoid faunas of Victoria. *Proceedings of the Royal Society of Victoria* 50: 221–243, 4 figs.

Biographical mention of Betty Ripper occurs in the following:

DARRAGH, T.A., KNIGHT, J.L. & TATTAM, C.M., 1976. *History of Geology in Victoria*. In The Geology of Victoria, J. G. Douglas & J. A. Ferguson eds Geological Society of Australia. Special Publication no 5, 1–9.

SHERRATT, T. & MCCARTHY, G., 1992. *A Guide to the Records of Edwin Sherbon Hills. Deposited with the National Library of Australia*. Australian Science Archive Project, Melbourne University, 149 pp. [N.B. 'Riffer' in error].

TURNER, S., 1994. Women in palaeontology in Australia. *In Useful and Curious Geological Enquiries Beyond the World. Pacific-Asia Historical Themes*. 19th INHIGEO Symposium, Sydney, July 4–8, 1994, D. F. Branagan & G. H. McNally eds, INHIGEO, 248–250.

TURNER, S., 1998. Women in paleontology in Australia. *In Sciences of the Earth. An Encyclopedia of Events, People, and Phenomena*, G. A. Good, ed., Garland Press, USA, 848–852.

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REFERENCES

BIRCH, W. D. ed., 2003. *Geology of Victoria*, 3rd edtn, Geological Society of Australia, Special Publication 23, 842 pp.

BRANAGAN ['D. F. B.'], 1975. Kathleen Sherrard. *The Australian Geologist* no. 8, Dec., p. 11.

CAMPBELL, K. S. W. & JELL, J. S., 1998. Dorothy Hill 1907–1997. *Historical Records of Australian Science*, 12: 205–228.

CLEEVELY, R.J., 1983. *World Palaeontological Collections*. British Museum (Natural History). Mansell Publishing Ltd, London Trustees. BMNH, 365 pp.

KELLY, F., 1993. Learning and teaching science. Women making careers 1890–1920. In *On the Edge of Discovery. Australian women in science*. F. Kelly ed., The Text Publishing Company: University of Melbourne, 35–75.

STEARN, C. W., WEBBY, B. D., NESTOR, H. & STOCK, C. W., 1999. Revised classification and terminology of Palaeozoic stromatoporoids. *Acta Palaeontologica Polonica* 44: 1–70.

SUMMERS, H. H., 1947. The teachers of geology in Australian Universities. *Journal and Proceedings of the Royal Society of New South Wales*. Clarke Memorial Lecture. 81: 122–146.

WEBBY, B. D. & ZHEN Y-Y., 1993. Lower Devonian stromatoporoids from the Jesse Limestone of the Limekilns area, New South Wales. *Alcheringa* 17: 327–352.

WEBBY, B. D., STEARN, C. W. & ZHEN Y-Y., 1993. Lower Devonian (Pragian-Emsian) stromatoporoids from Victoria. *Proceedings of the Royal Society of Victoria* 105: 113–185.

THE ROYAL SOCIETY OF VICTORIA

ABN 62 145 872

ANNUAL REPORT FOR THE TWELVE MONTHS ENDING 31st DECEMBER 2005

Council has the honour to present to Members the following concerning the activities of The Society during its 151st year.

PATRON	His Excellency, John Landy, AC, MBE Governor of Victoria

COUNCIL

OFFICE BEARERS

President	Assoc. Prof. B.G. Livett, BSc(Hons), PhD
Vice-President	Assoc. Prof. P.G.Thorne, BSc, PhD, DipPubPol, HonDEng(Melb)
Immediate Past President	Prof. N.W. Archbold, BA, MSc, PhD (deceased 28/11/05)
Honorary Secretary	Em. Prof. J.W. Warren, MA, PhD
Honorary Treasurer	Capt. W.J.W. McAuley, BSc, MScp, KCT(Scot), KSJ, RFD, JP, FRGS, FAIE
Honorary Librarian	Dr. D.A. McCann, DipAppChem, DipEd, GradDipLib, MEnvSc, PhD
Honorary Editor	Mr. M. Grover, BEd, BSc(Hons) (January-June) Mr. B.J. Walby, MA, MSc, CChem, MRSC, FIMA (July-December)
Honorary Research Secretary	Dr. P.G. Baines, BA(Hons), BSc, PhD

Members

Dr. W.D. Birch, BSc(Hons), PhD
Mrs. H.J. Gardiner BA
Mr. M. Harris, BSc(Hons)
Assoc.Prof. R.L. Hughes, PhD
Prof. A.P. Kershaw, BSc, MSc, PhD
Prof. J.F. Lovering, AO, MSc, PhD, FAA, FTS
Em. Prof. N.F. Millis, AC, MBE, MAgrSc, PhD, FTSE, FRSV
Prof. L. Selwood, MSc, PhD
Em.Prof. D.M. Stokes, BSc(Hons), PhD, DipEd, FEIANZ
Mr. B.J. Walby, MA, MSc, CChem, MRSC, FIMA
Mr. M. Williams, BSc, MS
Dr. A.L. Yen, BSc, PhD

Retirements

Mrs. H.J. Gardiner (resigned May 2005)
Mr. M. Grover, BEd, BSc(Hons)
Mr. M. Harris, BSc(Hons)
Em.Prof. D.M.Stokes, BSc(Hons), PhD, DipEd, FEIANZ

PRESIDENT'S REPORT

On behalf of Couneil, I am pleased to report for the year ended 31st Deeember, 2005.

During our 151st year, several important aetivities were eondueted.

In June, our Patron, Governor Landy weleomed delegates to our symposium on The Barmah Forest. This was held at Melbourne University. It was very well attended and brought together experts in the field of water management to review the speeial problems faeed by those living along The Murray. In Oetober, we were guests of La Trobe University (Mildura eampus) for a two day eonferenee on The Mallee. I would like to thank Counellor Dr. Alan Yen, Mr. Geoff Laeey and Dr. Tony Ladson for their exeellent arrangements (both seientifie and soeial) that ensured the sueeess of these conferenees. The findings will be published in our Proeeedings.

I am most appreeiative of the Hereulean task aehieved by Basil Walby (Honorary Editor) and Craig Robertson his assistant to bring us baek on traek with The Proeeedings. Their timely publication is eentral to our funetion and we look forward to regaining the high standard of past issues given the elose working relationship these two talented gentlemen enjoy.

2005 saw the launeh of VAST, a publieation highlighting the seientifie eontribution of RSV Members, past and present. I wish to thank Mr. Craig Robertson and Dr. Doug MeCann for their exeellent efforts in initiating and produeing this interesting newsletter.

Our applieation to mount two Summer expeditions to The Antaretie to provide an Edueation, Outreaeh and Communieation program for 200 young seientists from around The World the opportunity of engaging in a unique programme eondueted aboard a Class1 Ieebreaker during The International Polar Year (01 Mareh 2007–01 Mareh 2009) has been approved by The IPY Joint Committee in Cambridge; our planning is well advaneed. I wish to thank Captain Bill MeAuley (our Honorary Treasurer and Leader of RSV-INTREPID) and Mr. David Dodd for their superb efforts whieh have positioned us most favourably to be able to undertake these momentous voyages of seientifie investigation.

An important new initiative of Couneil, spearheaded by Prof. Lynne Selwood, is the establishment of The Soeiety's Post-Graduate Student Prizes in both The Biologieal and Physieal Seienees. Students will require to be in their seeond to third year of eandidature. There will be two annual prizes (one in The Biologieal Seienees the other The Physieal Seienees). A one page abstraet deseribing eaeh student's researeh will be required and applieations will elose at the end of May. Candidates will be judged on the basis of an oral presentation that will take plaee in August before a general audienee of The Soeiety. Two winners will be announeed on the day, eaeh reeeiving a eertifieate and $500.00. These prizes are open to all Student Members of The Soeiety. A speeial category of student membership has been established attraeting an annual subseription of only $35.00. Spread the word.

As diseussed under Aetivities I am delighted that so many of you have been regular attendees eaeh month and ean promise you an equally interesting program this year.

Our historie building is both a blessing and heavy responsibility. With the internal restoration and struetural repairs eompleted, I am delighted to report that the plans presented to Heritage Vietoria to provide a basement whieh The Soeiety so desperately needs have just been approved. This spaee will allow us to dedieate room for our now Exploration Gallery whieh will house a selection of our prieeless artefaets. Our thanks must go to The Exeeutive Offieer Camilla van Megen, Mr. Alan Lugton, and Honorary Treasurer Captain Bill MeAuley who provided the idea, impetus and oversight to enable this to happen. The external restoration works remain to be undertaken subjeet to finanee. Funding applieations have been made to the Federal and State Governments and The City of Melbourne. We remain hopeful.

Partieular thanks are due our Exeeutive Offieer, Camilla van Megen, for her tireless efforts in raising funds and drawing attention to the state of our Hall, and to our builder, Mr.Lugton for his commitment and oversight over the past twelve years.

A most successful and historie meeting was held at The RSV in November when we hosted the seeond eonvention of eaeh of The (six) Royal Soeieties in Australia (NSW, Tasmania, Vietoria, South Australia, Queensland and Western Australia) at whieh it was agreed (after vigorous debate) that syndieation was desirable in the interests of eaeh Soeiety in order to provide a national foeus. Harnessing our resourees in this way should enable a more effeetive means of advaneing the cause of Seienee for all eoneerned. A detailed agenda and eonstitution was drafted and tabled on the day by Couneillor Bill MeAuley (with the help of our Honorary Solieitors).

The draft constitution was adopted to formally establish **The Royal Societies of Australia** under the patronage of His Excellency The Governor General who, incidentally, is fully supportive of the notion. The Society will be limited by guarantee and the liability of its Members (the state-based Societies) will be limited. No amalgamation will take place and no one Society will be subordinate to another. The independence of each Society is guaranteed and is in fact wholly warranted. There will be no need to change the constitution of any state-based Society whatsoever.

The objects of The Society are:

1 the promotion and advancement of science and technology in Australia;

2 the promotion of public awareness, knowledge, and understanding of science and technology;

3 the promotion and advancement of science and technology education, research and application;

4 the promotion, encouragement and recognition of excellence in science and technology;

5 the provision of infrastructure to support the professional requirements and development of scientists; and

6 the publication and preservation of articles, books, journals, periodicals and other such documents relating to science and technology.

The R.S.A. promises a marvellous future for expanding our collective activities and scientific initiatives throughout The Commonwealth and beyond. It should permit Australia's six Royal Societies an opportunity to speak with a much louder voice on those matters of national import that surface from time to time, and with which we have (collectively) for whatever reason, failed adequately to address. The Society is indebted to Capt. McAuley who single-handedly laboured so long and hard to ensure success, and whose suggestion it was over four years ago that this Society sponsor the formation of The R.S.A. in the interests of each state-based Royal Society in The Commonwealth.

I am greatly indebted to the services of my fellow Councillors for their generous contribution to The Society. I wish to note our retiring Members of Council: The Society is indebted to Mr. Monty Grover who as Honorary Editor has contributed many years of invaluable service; Mrs. Helen Gardiner contributed to our activities during Science Week and increased the profile of The Society in numerous ways. Mr. Martin Harris has helped to extend our membership, encouraging younger candidates to join. Prof. David Stokes brought to Council his valuable experience working with The Innovation Council and made many valuable suggestions, acting as the devil's advocate on numerous occasions.

It is with great regret that I record the loss of our Immediate Past President, Professor Archbold. His devoted service to The Society will be long remembered. We have lost a friend, an academic and above all, a gentleman. Our sincere condolences go to his wife, Linda. A memorial symposium to honour Neil will be conducted later this year. Its findings will be published by The Society.

2004 ANNUAL GENERAL MEETING

The 150th Annual General Meeting was convened 10th March, 2005, prior to The Ordinary Meeting.

1 The Officers and Councillors elected at the Ordinary Meeting held on 8th December, 2004 were inducted for 2005.

2 The Annual Report and Financial Statements for 2004 were received and adopted.

3 Mrs. Marianne Kovassy, M.Acc, CPA, AAIM, was re-appointed Honorary Auditor.

FUNDRAISING

The Society wishes to acknowledge once again the generous donation of $50,000 from The Vera Moore Foundation together with donations received from our Members, for which Council is very grateful.

The Society also wishes to acknowledge the generous sponsorship for the Barmah and Mallee Conferences by the Department of Sustainability and Environment, Department of Primary Industries, The Murray Catchment Authority and La Trobe University. Their generous donations will underpin the publication of the Proceedings.

We enjoy 100% tax exempt status and I encourage you to think of The Society generously when arranging your affairs and considering bequests.

The Society needs your continued support not only to maintain our varied scientific programme, but also to keep the roof over our heads. We are the only Royal Society in Australia that has its own home and through our Executive Officer's good promotion our Hall is in demand. I encourage you to think of The RSV for your next function and to direct others to our web page for photographs of our elegant function rooms and facilities.

We are hoping to raise sufficient funds to complete the restoration of the exterior and again I encourage you to think of The Society when considering any bequest.

We welcome your suggestions for increasing our corporate membership and remember that as a member you are able to nominate new members. A good way to introduce a prospective member to The Society is to bring them to one of our activities.

THE ROYAL SOCIETY OF VICTORIA FOUNDATION ASSISTING THE PROMOTION AND ADVANCEMENT OF SCIENCE AND TECHNOLOGY (RSVF — APAST)

The inaugural meeting was held in this Hall 4.00 p.m. Wednesday, 26th October last. It comprised 11 Board Members:

RSV Councillors
Prof. Neil Archbold
Assoc.Prof. Bruce Livett
Prof. John Lovering
Capt. Bill McAuley
Em.Prof. Nancy Millis
Assoc.Prof. Peter Thorne
Em.Prof. Jim Warren

Eminent Non-RSV Councillors
Mr. Logan Armstrong (Chairman)
Sir Andrew Grimwade
Mrs. Caroline McGlashan
Lady Primrose Potter
Mr. Darrell Jackson tendered his apologies.

Five distinguished citizens have agreed to act as Patrons:
Prof. Suzanne Cory
Sir Peter Derham
Laureate Prof. Peter Doherty
Dr. Phillip Law
Prof.Em. Sir Gustav Nossal

The Foundation is limited by guarantee and has the general aim of directly assisting The Society in fulfilling its Charter in respect of the promotion and advancement of Science and Technology, and provides a 100% income tax exemption (along with The Society) for any person making a donation to it. The Society's Honorary Treasurer, Capt. McAuley has the distinction of being the first person to make a donation to The Foundation. May others soon follow.

The Chairman concluded this historic meeting by remarking on the possibilities that lay ahead and suggested that success was within The Foundation's grasp notwithstanding the ambitious scope of its development strategy.

Mr. Armstrong suggested that careful consideration be given by Council to selecting three priority tasks which could be dealt with initially to satisfy the requirements of The Society.

He then adjourned the meeting and invited those present to join him in The John Green Room for light refreshments.

FELLOWS: (INDUCTED 2005)

The Society congratulates **Dr. Hilary J. Harrington** and **Dr. Murray J. Littlejohn** elected as Fellows of The Royal Society of Victoria.

Dr. Harrington has a distinguished career in geology commencing in New Zealand with the discovery of 500 km of horizontal movement on The Alpine Fault which proved that significant continental drift could and did occur. Participating in The IGY (1957–58) he led the first two New Zealand expeditions to Antarctica and two later expeditions. Notable research contributions followed on The Tasman Fold Belt System, as Principal Investigator for NASA in Australia, Co-leader of Indonesia's Bouguer Gravity Anomaly Mapping project, and leader of The BMR/CSIRO/States Program to prepare an overview of Permian coals and sedimentary basins from Tasmania to Cape York. Attached to The CSIRO's Division of Mineral Physics he arranged for NASA's ERT Satellite to be switched on over Victoria which became the first region to be covered by space imagery. "A Geology of Victoria in Relation to Satellite Imagery" was later published by The CSIRO and The Geological Survey of Victoria. He has made a progressive and focused study of the geology from Antarctica through Australia to Indonesia on our part of the globe.

Dr. Littlejohn is an eminent Australian zoologist and a pioneer in the application of audio recording to animal communication, most notably, acoustic signalling on frog species in temperate southern Australia and the southern United States. In addition to his work on acoustic communication and the general biology of frogs, Dr. Littlejohn has published widely in a number of areas of evolutionary and behavioural biology including species concepts, patterns and processes of speciation, hybrid

zones and zoogeography. Dr. Littlejohn's contributions to biological research have received international recognition, especially in the United States, and he has twice been the recipient of a Fullbright Scholarship.

2005 PROGRAMME

This year the Society continued its program of evening lectures on the second Thursday of every month from March to December. These lectures are free to Society members and guests, and cover a broad range of topics that span most areas of science, with the opportunity to converse with the speakers at a buffet dinner after the event. In general, these lectures were of a very high quality with most speakers being recognised experts in the field discussed. Audiences were near to or exceeded capacity on most occasions, with some seating being provided in the Library to cope with the overflow on some occasions. The list of speakers and topics is given below, and the abstracts are available on the Society's web page.

The season opened with a controversial presentation by Mr. Bob Foster, a retiring former Councillor, who presented an argument that the observed global temperature increase over the past century can be attributed to the sun. The world's leading experts on the sun disagree with him, but the talk was entertaining and served to remind us that aspects of the climate change debate are still controversial. The April presentation was on firmer ground, where Prof. David Jameson (The University of Melbourne Physics Deprtment) talked about Einstein's legacy, in the 100th anniversary of Einstein's "annus mirabilis" of 1905. The theme of the physical sciences was continued in May, with a description of the chemical properties of the deep-ocean submarine hot springs in our region of the Southwest Pacific, and elsewhere, by Timothy McConachy of CSIRO. There is now quite a long list of such sites, and possibilities of mining some of the associated ore bodies (for gold, copper, zinc and silver) are being explored. The drift in topics toward geology continued in June with a presentation by Dr. and Mrs. Ross Ramsay on the manufacture of the first porcelains in the English speaking world in the 18th Century.

The August lecture by Dr. Harry Schaap of Energy and Environmental Management Services on "Energy", discussed the various options for the future (coal, uranium, renewables), and the problems associated with each.

The last half of the year was dominated by talks based on biology. In July Keith McLean (Vision CRC and CSIRO) talked about new techniques for correcting faults in human vision, particularly "presbyopia", or deterioration due to aging. A technique termed "synthetic corneal onlay" is currently undergoing Phase 1 of clinical trials and shows great promise for widespread future use. In September, Prof. Sharon Lewin (Monash University and the Alfred Infectious Diseases Unit) described the properties of the various forms of viral hepatitis. The two most dangerous forms, HBV and HCV, continue to have increasing global incidence causing chronic life-long infection, illness and death. The October lecture by Dr. Mark Norman (Museum Victoria) entitled "Monsters of the Deep" contained a large number of fascinating photographs of bizarre creatures from the ocean below the photic zone, well below the more familiar fish and plankton communities in the surface layers penetrated by sunlight. Although the number of creatures in this dark cold region of very high pressure is relatively very small, it is remarkable that this region supports balanced and varied interdependent living communities. In November, Karina Kelly (ABC Catalyst Program presenter) talked about "The New Dark Age of Science", in which independence of thought is not encouraged by funding agencies these days. This philosophical presentation generated a great deal of discussion and was one of the best attended talks of the year.

The final presentation of the year was by Prof. Pauline Ladiges (School of Botany, The University of Melbourne), The Society's Medallist for 2005. She discussed the evolution of the Australian Flora on geological time scales, and how the topic of plant taxonomy has been revolutionised by DNA analysis techniques. The history of various plant species (particularly trees) and the times in which they first became distinct are slowly being mapped out and related to the climate history of the continent.

In association with the Field Naturalists Club, a presentation on "Applications of Geophysical Information To The Selection of a Representative System of Marine Protected Areas in Southeastern Australia" was given by Dr. Peter Harris (Geoscience Australia) on 22nd September, who provided interesting insights into the criteria used to determine the areas chosen for Marine Park protection.

THE ROYAL SOCIETY OF VICTORIA AND GEOLOGICAL SOCIETY OF AUSTRALIA INC. (VICTORIA DIVISION) A. W. HOWITT LECTURE

The second A.W. Howitt lecture, held with the Geological Society of Australia, entitled "Oceans of Mars" was given by Ms. Marion Anderson (Monash University Geosciences) on 22nd June on the exploration of Mars by roving vehicles from recent space probes. The two vehicles on opposite sides of the planet are still operating long after their expected lifetimes, and have succeeded in their principle objective, namely determining whether there was once water on Mars, in the affirmative.

BARMAH AND MALLEE SYMPOSIA

Two Regional Conferences were held during the year. Both were well attended and very successful, with many papers that will appear in the proceedings. The first was on the Barmah-Millewa Forest and was held at the University of Melbourne on 18–19th June, and the second was on the Geological, Biological and Cultural Evolution of the Mallee, and was held in Mildura on 10–11th September. These meetings continue the long tradition of The Society in furthering knowledge of the Victorian districts and regions.

2005 PROGRAMME

Monthly meetings:

10 March	Mr. Bob Foster, Director, Lavoisier Group **"CLIMATE CHANGE: IT'S THE SUN, AFTER ALL!"**
14 April	Prof. David Jamieson, School of Physics, University of Melbourne **"EINSTEIN'S LEGACY — PAST, PRESENT, FUTURE"**
12 May	Dr. Tim McConachy, CSIRO Exploration & Mining **"SUBMARINE HOT SPRINGS AND MINERAL DEPOSITS IN THE SOUTH-WESTERN PACIFIC RIM OF FIRE"**
9 June	Dr. Ross Ramsay, Former Academic, Deakin University and Mrs. Gael Ramsay, Deputy Director, Ballarat Fine Art Gallery **"CHEROKEE CLAY: FORENSIC SCIENCE IN THE SEARCH OF THE EARLIEST PORCELAINS MADE IN THE ENGLISH-SPEAKING WORLD"**
14 July	Dr. Keith McLean, Eureka Winner Project Leader Biomaterials, CSIRO Molecular Science Ophthalmic Biomaterials for Correcting Vision **"FUTURE VISION: OPHTHALMIC BIOMATERIALS FOR VISION CORRECTION"**
11 August	Dr. Harry Schaap, Former General Manager, Sustainable Energy & Environment, Energy Supply Association of Australia **"RENEWABLES AND LOW EMISSION TECHNOLOGIES: CAN THEY EVER MAKE THE GRADE?"**
8 September	Dr. Sharon Lewin, Department of Infectious Diseases, Alfred Hospital **"THE ABC OF VIRAL HEPATITIS"**
13 October	Dr. Mark Norman, Senior Curator (Molluscs), Museum Victoria **"MONSTERS OF THE DEEP: THE BIZARRE LIVES AND BEHAVIOURS OF DEEP-SEA ANIMALS"**

10 November Ms Karina Kelly, Presenter, Catalyst, ABC TV
"THE NEW DARK AGE OF SCIENCE: HOW INDEPENDENT THINKERS ARE AN ENDANGERED SPECIES"

8 December Prof. Pauline Y. Ladiges, The Royal Society of Victoria 2005 Medallist (Biological Sciences Non-Human), Head, School of Botany, The University of Melbourne
"EVOLUTION OF AUSTRALIAN FLORA – From Rainforest to Desert"

THE SOCIETY'S RESEARCH MEDAL FOR 2005

The 41st Award of The Society's Medal for Scientific Research (The Royal Society of Victoria Research Medal) was awarded to **Professor Pauline Y. Ladiges**, Head, School of Botany, The University of Melbourne. The presentation to Prof. Ladiges was made on 8th December, 2005.

STUDY GRANT

From the Estate of the late Mr. E.D. Gill, a gift of $4,000 was bequeathed to The Society in 1987. The Council invested the money and established "**The E.D. GILL MEMORIAL STUDY GRANT**" to encourage young scientists who may need financial assistance.

In 2005, a grant of $1,000 was awarded to **Miss Hannah Humm Nair**, who aims to ascertain the origin of a shell assemblage first discovered by Edmund Gill on the Point Ritchie headland, Warrnambool, Victoria. Congratulations are extended to Ms Nair.

THE ROYAL SOCIETIES EUREKA PRIZE FOR INTER-DISCIPLINARY SCIENTIFIC RESEARCH

The 2005 Royal Societies of Australia Eureka Prize ($10,000) was won by the Astrobiology Research Team from the University of New South Wales and Macquarie University for pioneering research on the stromatolites ('living rocks') from Shark Bay, Western Australia. These formations are analogs of the earliest life on Earth, extending back more than 3 million years. This research has dramatically enhanced our understanding of these complex biological systems at many levels. They show great diversity in their resident microbial communities, as well as showing unique stress responses to salinity and geochemical records of past environmental changes. One of the research team members, **DR. BRENDAN BURNS, ASSOCIATE PROFESSOR BRETT NEILAN** and **PROFESSOR MALCOLM WALTER** will be asked to present their findings at a meeting of The Society in 2006.

MEMBERSHIP 2005

Elected	182
Transfers to Life Membership	0
Transfers to Life Membership Honoris Causa	0
Resignations	15
Deaths	7
Removed from Register (failure to pay subscriptions)	9
Total Members	775

Corporate

Australian Delphi User Group Inc.
Davies Collison Cave
School of Philosophy (Melb) Inc.
Walter and Eliza Hall Institute of Medical Research

VALE

The following deaths are recorded with deep sympathy and regret:

Prof. Neil W. Archbold
Assoc.Prof. David H. Ashton
Thomas Colchcedas
Dr. Clive Coogan
Alan Gordon
Donald A. Harris
J. L. Perdrix
Colonel Peter M. Robinson
Charles H. G. Smith

PROCEEDINGS

The following papers included in Volume 117 Numbers 1 and 2 are listed below:

DENIS J. CARR
Two new Bryophytes in Victoria.

SECTION B: Other Proceedings

CORRIGENDA
Corrigenda to Proceedings Volume 116

TRANSACTIONS:

PETER N. JOUBERT
Some remarks on the Sydney-Hobart race (reprinted from Vol. 116(2) with corrigenda)

GREG MORTIMER
Antarctic tourism — past, present and future

PHILLIP LAW
The jubilee of the establishment of Mawson Station

ADRIAN WELLS
Aliens in our waterways

BRIAN SHARP
Local Government and Natural Resource Management

MARK WARNE
Supplementary notes on the subgenus *Loxocythere (Novoloxocythere)* Warne and some comparable ostracod taxa (includes corrigenda for Vol. 116(2))

NANCY MILLIS
Yvonne Aitken, AM, DAgr Sc, Fellow of Royal Society of Victoria: 17.10.1911 – 29.11.2004

KARINA KELLY
Address to The Royal Society of Victoria, 10 November 2005

SUSAN TURNER
Dr Elizabeth Arnold Ripper 1909-2004: early 20th century Victorian palaeontologist. In Memoriam

Volume 117 Number 1 was distributed in February 2006. Volume 117 Number 2 and Volume 118 will be published in 2006.

OTHER PUBLICATIONS:

Spiders and Scorpions Commonly Found in Victoria by Ken L. Walker, Alan L. Yen and Graham A. Milledge.

The Yarra: A Natural Treasure by David Beardsell and Cam Beardsell.

Gemstones and Minerals of Victoria by William D. Birch and Dermot A. Henry (joint publication with The Mineralogical Society of Victoria).

Volcanoes in Victoria by William D. Birch.

Education, Antarctica, Marine Science and Australia's Future, Proceedings of the Phillip Law 80th Birthday Symposium.

The Royal Society of Victoria from Then, 1854 to Now, 1959 by R.T.M. Prescott (reprinted).

Facsimile edition of the Inaugural Addresses of the First Presidents, Mr. Justice Redmond Barry, President of The Victorian Institute for the Advancement of Science, and Captain Andrew Clarke, R.E., Surveyor General, President of The Philosophical Society.

Facsimile edition of The Transit of Venus 1874 by R.L.J. Ellery

LIBRARY

For over 150 years The Royal Society of Victoria (RSV) has received material "on exchange" in subject areas such as biology, zoology, geology, palaeontology and other natural sciences from learned societies, academies of science, and other scientific institutions from all over the world. Serials make up the greater part of the collection. Since 2000 most of The RSV Library Collection has been housed at Deakin University, Melbourne Campus, 221 Burwood Highway, Burwood.

A minor portion of The Society's library collection consisting mainly of older periodicals and publications from the various allied Royal Societies from around Australia as well as some general books and rare books is housed in The Society's building.

In June 2000 Deakin University entered into arrangements with The Royal Society of Victoria to house and catalogue this valuable collection. That agreement has expired and The Society is negotiating a new agreement with Deakin University. The Late Professor Archbold authorised Captain McAuley to oversee the drawing of a new agreement and this draft is being reviewed by our Honorary Solicitors (Messrs Blake Dawson Waldron). It should be settled shortly.

The cataloguing project at Deakin University began in September 2002 and was finished by the end of 2003. The cataloguers identified some 1385 titles in the collection, mostly serials, with the number of individual items running to several thousands. It is estimated that at least 35% of the material held in this collection is unique to Australia. The catalogue for The Society's collection is now accessible on-line via the Deakin University Library web-site.

Access to the collection is available by appointment and inter-library loans and photocopying facilities are available. It is recommended that anyone wishing to access or consult the collection's hardcopy should make an appointment with:

Ms Margit Gailis Tel: (03) 9251 7197 Email: gai@deakin.edu.au or

Mr Mark Steinkamp Tel: (03) 9251 7426 Email: mark.steinkamp.edu.au.

Usually 24 hours notice is required if a user wants access in order to allow the librarians to check if the required material is available as requested.

In 2005 there continued to be a moderate but steady demand for use of our collection. There is an ongoing demand for interlibrary loans and for direct access to hardcopy material often by PhD students. The Deakin University librarians report that there is a growing recognition within and outside the University of the value and importance of The RSV collection.

Doug McCann
Honorary Librarian

THE SOCIETY'S HALL

It is pleasing to note that numerous organisations conducted over 300 meetings in its Hall during the year, apart from The Society. This result is directly attributable to the promotional efforts of our Executive Officer, Camilla van Megen. In addition to the aforementioned The Society hosts a variety of other like-minded bodies, which, without pro bono support by us, would almost certainly wither on the vine.

METEOROLOGICAL OBSERVING SITE:

The Commonwealth Bureau of Meteorology continues its lease.

CITY OF MELBOURNE

The Council wishes to acknowledge with gratitude the continued maintenance and refurbishment of the grounds of The Society as part of the City of Melbourne's open space system.

GOVERNMENT OF VICTORIA GRANT

The Council acknowledges with gratitude the grant of $10,000 received from the Government of Victoria towards the cost of publishing the "Proceedings of The Royal Society of Victoria".

TREASURY

The Society's accounts (as at 31st December 2005) comprising its Balance Sheet, Statement of Income and Expenditure, and Schedule of Investments have been confirmed by Mrs. Marianne Kovassy, The Honorary Auditor; both she and The Society's Administration Officer, Mr. Viv Martin (who prepared the accounts for validation) deserve considerable credit.

Balance Sheet

Over the reporting period (01 January – 31 December 2005) Members Funds increased by $65,938.00, Current Assets by $89,581.00 with Fixed Assets remaining static.

Investments (at cost) reduced by $55,409.00 with Current Liabilities standing at $37,878.00: a healthy reduction of $31,837.00 from the previous year.

All shares held as direct investments were sold at a capital gain of $1,526.00. Cash at Bank has increased due to the sale of shares.

The loan of $150,000.00 extended to The Society by The Heritage Restoration Fund (Victoria) was repaid in its entirety with the final payment made in November.

The increase of $7,694.00 in Sundry Creditors is due to monies outstanding to produce The Proceedings. Stock – Publications has been calculated at original cost.

Income & Expenditure Statement

Our accounts are reported on a "non-cash" basis, and, it is with some little pride and a measure of satisfaction that I have the honour of reporting for the

first time in recent memory, a **surplus** (after expenditure on major building works) of **$67,654.00** due in large measure to almost all items of a revenue nature increasing.

Income
Total Income has risen by (71%) to $188,963.00. Income from Interest and Dividends is down by 30% – reflecting the sale of shares. The income from Projects is also down (93%), principally because no book fairs and the like were conducted by The Society in 2005. However a substantial boost in income (less expenditure) was derived from both The Barmah Forest and Mallee Symposia to the tune of almost $40,000.00. Gross income from Seminars and Symposia rose by nearly 380%. The rental from the commercial hire of our Hall increased 190%. Sundry Income largely attributable to Parking rose by nearly 200%.

Expenditure
Total Expenditure rose (22%) by $66,432.00 over the 12 months. The increase in Building Fund-Raising of 82% is attributable to the establishment of The Society's Foundation. Insurance premiums were reduced by 33% and expenditure on Projects fell generally by 34%.

The costs of our Proceedings have risen sharply by $18,500.00 (554%) – due mainly to a "catch-up" payment for the previous year being recorded in the present reporting period.

Schedule of Investments
The market value of The Discretionary Share Portfolio (managed for The Society by The Ralton Group Ltd) has increased by $29,887.00 – a most pleasing result.

Observations
The financial position of The Society is **at present** satisfactory. However, circumstances need change little to oblige a return to reporting a deficit in 12 month's time. Procul omen abesto. Nil desperendum though because I have the honour to be and remain your humble and obedient servant.

W.J.W. McAuley
Honorary Treasurer

ACKNOWLEDGMENTS:

The Society's sincere thanks and appreciation is recorded to those people and organisations that contributed their valuable assistance to The Society during the year; notably:

– Mr. J.W. Logan Armstrong, Honorary Solicitor
– Mr. Arthur Apos, Messrs. Blake Dawson Waldron, Honorary Solicitors
– Mr. John Selak, Senior Partner, Messrs. Ernst & Young, Honorary Accountant
– Mr. Alistair Urquhart, Affairs of State
– Lt. Col. Richard Lightfoot, Honorary Engineer
– Mr. Paul Haysey, F.W. Holst & Co
– Mr. Douglas Graeme, QC, Honorary Counsel
– Mr. Craig Robertson
– Mrs. Marianne Kovassy, Honorary Auditor
– The Ralton Group Ltd., Honorary Financial Investment Advisers
– Mr. Marcus van Megen, IT Consultant
– Mr. Alan Lugton, S. & L. Building Services Pty. Ltd.
– Donors to The Society's Building and Library Funds
– Volunteer assistance with the Newsletter and other tasks — Wendy Coates,
– Leon Costermans, Barbara Day, Ivo Dean, Ian Farnsworth, Richard Franklin,
– Maretta Frolley, Jim Lowden, Elaine Muir, Redmond Nolan, Ken Simpson and
– George Snelling.
– Ms Kathy Powers, Degrees Catering

ADMINISTRATION

Our Executive Officer, Camilla van Megen, has continued to very skillfully manage The Society during 2005. Our staff, together with their duties, are listed below. Council expresses its appreciation for their dedicated and efficient work on behalf of The Society.

– Ms Camilla van Megen	Executive Officer
– Mr. Vivian Martin	Administration Officer (part time)
– Ms Julie Dunn-	Bookkeeper (part time)
– Mrs. Janet Jackson-	Secretary (part time)
– Norman and Janet Minge-	Property Attendants (January-June)
– James McArthur-	Property Attendant (July-December)

Without the devoted service of our Executive Officer, Camilla Van Megen, and her obliging and talented office staff, it is unlikely that The Society would continue to function. Many members have made comment to me over the past year as to how much they appreciate the friendly and informed service that Camilla, Viv Martin, Janet Jackson and more recently Julie Dunn have provided. I wish also to acknowledge the valued assistance by Marcus van Megen for his expertise in assisting our speakers with their Powerpoint presentations. Marcus also supervised the smooth running of our après talk suppers, dinners and social activities with the assistance of our caretaker, James McArthur who also takes pride in attending to the care of the building. Thank you all for your continued and excellent service to The Society.

CONCLUDING REMARKS:

Looking back on our accomplishments over 2005 is most heartening, and gives me every confidence that The Society is living up to its Charter, namely the Promotion and Advancement of Science and Technology.

The year ahead looks equally exciting following the establishment of our Foundation and priority given to securing the funds required to mount our two expeditions to The Antarctic and embodying the Education, Outreach and Communication programme raised for The International Polar Year. These are ambitious undertakings and will require immense input and energy. Your help will be needed to ensure success; there will be a variety of important tasks for which volunteers will be required. The Society has a pressing need for financial assistance and I implore you to think deeply and to give generously knowing that through our 100% tax deductible status you can record any donations to The Society as a legitimate deduction. It may be you are about to review your financial position generally, in which case I would urge you to include The Society.

Thank you for your continuing support. I look forward to serving as President for the balance of this year knowing I possess an energetic and loyal Council which will provide me expert advice and make my role one that continues to be enjoyable and satisfying. I urge you to introduce friends to The Society and to bring likely young candidates for membership to our meetings on a regular basis. The Society **must** engage Youth if it is to prosper.

This Report is approved by Council for presentation and adoption by Members at The Annual General Meeting to be held Thursday, 9th March, 2006.

BRUCE G. LIVETT
President

PROCEEDINGS

OF THE

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INSTRUCTIONS FOR AUTHORS

Papers considered for publication may be: Reviews, Reports of experimental or descriptive research, or Short Communications. Length of papers may vary but Short Communications should not exceed 1500 words. When an author submits a manuscript for consideration, it is assumed that it has never been published or is under consideration for publication elsewhere.

SUBMISSION

The original and two copies of the typescript and all tables and figures should be submitted to the Executive Officer, Royal Society of Victoria, 9 Victoria Street, Melbourne, Victoria, 3000. Use International A4 bond paper, printed on one side only. In a letter of transmittal, give the names and addresses (postal and email) of the author or co-authors.Also give the names, addresses and email addresses of three persons not directly associated with the work and outside the author's institution, who could act as referees. For all papers, presentation of the final manuscript on word-processed floppy disk is essential as well as a hard copy. Authors or their institutions may be requested to contribute towards the cost of publication of the paper and in the case of very long papers, such contribution is mandatory. It will assist reviewers if related papers recently published or submitted elsewhere accompany the submitted manuscript.

FORMAT

All manuscripts should be written in clear and concise English. Use double spacing throughout; leave 30 mm margins around the text; number all pages. All measurements are to be expressed in SI units (eg µm, mm, m, km but not cm) and standard symbols and abbreviations used. Note, Ma refers to a date (eg 25Ma) not a time interval, which is written as 25 million years. When a number does not refer to a measurement it should be spelt out except when it is greater than nine. Wherever possible fractions should be written in the form x/y.

Geological papers must follow the Australian Code of Stratigraphic Nomenclature and should cite geological maps in the text with italics for the 1:63 360 series and full caps for the 1:250 000 series. New stratigraphic names should be registered with the Geoscience Australia (GA) Australian Stratigraphic Names Database. The GA website "How to define a lithostratigraphic unit" (http://www.ga.gov.au/minerals/strat_names/) is a useful guide.

The *Proceedings* uses Australian spelling according to the latest edition of the *Macquarie Dictionary* and where there is optional spelling for words we use the form used by Victorians traditionally. For example we use the following spelling; color, honorary, program.

Authors should follow the layout of headings, tables and illustrations as presented in a recent issue of the *Proceedings*.

Papers should be organised as follows:

1. *A brief title*, capitalised and, if possible, beginning with a key word.
2. *The name and address of the author(s)*, with numerical superscripts to distinguish addresses of multiple authors.
3. *A full reference to the paper*, leaving space for the printer's additions.
4. *A short abstract* of not more than 200 words describing the results (rather than the contents) of the paper.
5. *Up to 5 key words.*
6. *The main text.* Capitalise the first word of the introductory paragraph; do not use the heading 'Introduction'. Within the text up to three grades of headings may be used, typed as follows:

GRADE ONE HEADING

Grade two heading

Grade three heading. Followed by running text on the same line.

Refer to papers illustrations in the text as "Fig. 1A, B", "Figs 1, 2" or "Figs 1–4", and indicate in the margins where the illustrations should be placed. Cite references in the text as Archbold (1998), (Archbold et al 1998) or (Archbold 1998: 2, fig. 1); multiple citations should be arranged chronologically. All references cited in the text must be listed at the end of the paper. Footnotes in the main text are not allowed. Where there are multiple authors for a reference, "et al" is used, and is not italicised.

In taxonomic works, synonymies should be of the same format as the following examples, with a dash preceding authors' names except in the case of reference to the original description.

Eudendrium generalis Lendenberg 1885: 351, pl. 6. — Lendenberg 1887: 16.

Eudendrium generale. — Hartlaub 1905: 515.—Watson 1985: 196–200, figs 40–52.

non *Eudendrium generale*.—Watson 1982: 89, pl. 10, fig. 3.

Eudendrium lendenfeldi Briggs 1922: 150.—Rosler 1978: 104, 120, pl. 20, figs 1–3.

Note that plate and figure numbers, etc. originally given in Roman numerals should be transliterated into Arabic figures; this is also the case in the main text and in the references.

7. *Acknowledgements*. The source of financial grants and other funding, as well as the contribution of colleagues or institutions, should be acknowledged. These should follow the main text and be as brief as possible.

8. *References*. These should conform in arrangement to the examples below. Journal titles must be cited in full as they appear on the title page.

CURTIS. N. P., 2001. Germination of *Xanthorrhoea australis* using treatments that mimic post-fire and unburnt conditions. *Proceedings of the Royal Society of Victoria* 113(2): 237–245.

BERGSON, H., 1928. *Creative Evolution*. MacMillan and Co., Limited, London, xv+425 pp.

ROSEN, B.R. & TURNSEK, D., 1989. Extinction patterns and biogeography of scleractinian corals across the Cretaceous/Tertiary boundary. In *Proceedings of the Fifth International Symposium on Fossil Cnidaria including Archaeocyatha and Spongiomorphs*, P.A. Jell & J.W. Pickett, eds, Association of Australasian Palaeontologists, Brisbane, Queensland, 355–370.

Any other type check recent copies of the proceedings.

Personal communications and unpublished data are not to be listed in the reference list but should be mentioned in full in the text (eg P. Brown pers. comm. 2002).

9. *Tables and Figures*. Each table with its title should be typed on a separate sheet. A separate sheet should also be used to list captions to figures in numerical order.

ILLUSTRATIONS

These must be designed for one or two column width (67 mm or 140 mm); maximum length is 193 mm. Composite Figures should be labelled A, B, C, etc. (not a, b, c). Oversized illustrations, tables or maps may be accepted for publication as foldouts only if the author meets all costs involved in their production. Maximum size for foldouts is 193x285 mm.

Final submission of black and white figures electronically is encouraged as long as it is in a readily acceptable format (JPEG, TIFF, emf, wmf, pcx, pct, wpg, cdr). These can be supplied on 3.5" floppy disks, zip disks or CD (especially for figures with any grey shades) and accompanied by a high quality hard copy. Digital files must be supplied at a resolution of at least 600 d.p.i. at full size.

PROOFS

Authors will normally receive an 'Adobe Acrobat PDF'version of the mock page proofs; this is for the purpose of correcting printer's errors and not for altering the wording or substance of the paper. This should be returned to the editor within 72 hours. If absent, authors should arrange for a colleague to check and return proofs to the editor on their behalf. Authors will be charged for excessive alterations at this stage.

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